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(54) Title: HIGHLY EFFICIENT CONTROLLED EXPRESSION OF EXOGENOUS GENES IN <i>E. COLI</i>		
(57) Abstract <p>The invention relates generally to recombinant methods and materials for effecting the microbial production of useful polypeptides. More particularly, the invention relates to expression vector systems which utilize a translational repressor system, and transcriptional control proteins to provide a highly efficient, tightly regulated, staged inducible promoter system capable of expressing exogenous genes, including toxic genes, in <i>E. coli</i>.</p>		

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HIGHLY EFFICIENT CONTROLLED EXPRESSION OF EXOGENOUS
GENES IN *E. COLI*

FIELD OF THE INVENTION

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The present invention relates to new and improved expression vector systems capable of expressing exogenous genes, including toxic genes, in *E. coli* and other host cells. More specifically, the invention relates to highly efficient, tightly regulated expression vector systems which utilize the bacteriophage MS2 coat protein (MS2CP) and MS2 recognition site to control translation of the mRNA for any cloned gene in a host cell. In addition, the invention relates to expression vector systems which utilize transcriptional control proteins, e.g., *motA* and *asiA* of bacteriophage T4, to regulate transcription and provide a staged inducible promoter system which is much less complicated and much more versatile than the non-staged systems previously described.

BACKGROUND OF THE INVENTION

Prokaryotic cells have become the system of choice for expression of cloned genes encoding eukaryotic and prokaryotic polypeptides, and numerous expression systems exist for expression of gene products in bacteria. The expression of genes in *E. coli* has become established as a key technique in the understanding of molecular processes and *E. coli* expression systems have become a standard and popular method for the production and large-scale purification of exogenous proteins. Importantly, the technology has provided a source of proteins in a quantity and quality that was previously difficult, or impossible, to achieve through isolation from natural sources.

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A number of patented expression systems for use in bacterial hosts have been described. In some instances, the expression systems described relate to generalized expression systems, while in other
5 instances, the patented expression system is designed to allow relatively tight regulation, or is individually tailored for expression of a particular protein. Examples of such patents include U.S. Patent No. 4,767,708 (construction of recombinant vector
10 containing a cloned bacterial DNA polymerase I under the control of a positively regulated foreign promoter); U.S. Patent No. 4,503,142 (construction of a class of cloning and expression vectors based on the use of the lac promoter/operator of *E. coli*); and
15 U.S. Patent No. 4,578,355 (use of the P_L promoter of bacteriophage lambda to construct high level expression vectors).

Another widely used expression system, referred to as the pET vector expression system, makes
20 use of the powerful T7 RNA polymerase to transcribe genes of interest; Studier et al., *J. Mol. Biol.*, 189:113-130 (1986). T7 RNA polymerase is highly selective for its own promoters, and no T7 promoters are known to be present in the DNA of *E. coli*. T7 uses its
25 highly selective polymerase to direct transcription to its own DNA rather than to host DNA during infection, and a relatively small amount of T7 RNA polymerase provided from a cloned copy of T7 gene 1 is sufficient to direct high-level transcription from a T7 promoter
30 in a multicopy plasmid. Moreover, T7 RNA polymerase is at least 5 times more active than *E. coli* polymerases; *Id.* Many heterologous proteins have been successfully expressed in high yields using the pET system; see, e.g. Dietrich et al., *Eur. J. Biochem.*, 201:399-407
35 (1991); Lathrop et al., *Protein Expr. Purif.*, 3:512-517

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(1992); Aukhil et al., *J. Biol. Chem.*, 268:2542-2553 (1993).

Unfortunately, these and other reported expression systems still suffer, to a greater or lesser degree, from such things as: 1) uninduced expression resulting from promoter leakiness; 2) inability to control expression to the extent necessary when the gene product will kill or otherwise seriously damage the host cell if expressed (more typically associated with expression of eukaryotic genes in bacteria); 3) the need to rely for induction of expression on either the host's biochemical responses or expensive or otherwise inadequate induction mechanisms; 4) inability to express gene of interest at sufficient levels; and 5) plasmid instability. Until such problems are adequately addressed and successfully overcome, the full potential of such expression systems will not be fully appreciated or utilized.

All known inducible promoter systems have a residual level of activity or "leakiness" which leads to the inappropriate transcription and expression of the gene being cloned under the control of the promoter. In most cases, this is not a problem because the gene product being produced is well tolerated by the cell, i.e., the gene product is non-toxic. However, in instances where the gene product being produced is toxic or even lethal to the cell, even these small amounts of expression can be detrimental. In fact, there are certain toxic genes that have been characterized as "unclonable" because they are unstable in any cloning vector.

Studier, F.W., *J. Mol. Biol.*, 219:37-44 (1991) addressed the problem of leaky expression in the pET vectors by developing the Lys series of vectors. These vectors harbor the gene for T7 lysozyme, which binds the T7 RNA polymerase present in the uninduced

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cell and prevents it from transcribing target genes. Dubendorff and Studier, *J. Mol. Biol.*, 219:45-59 (1991) addressed the problem by providing additional copies of lac operon control elements in the pET plasmids. Brown
5 et al., *Gene*, 127:99-103 (1993) used induction by infection with a mutant T7 phage to successfully clone the toxic *POL3* gene. Unfortunately, these and other reported systems fail to completely alleviate the
10 leakage problem or suffer from the problems of plasmid instability and cell lysis associated with high levels of lysozyme and/or phage infection.

The present invention addresses and overcomes the problem of promoter leakiness by utilizing the translational repression capabilities of the
15 bacteriophage MS2 coat protein. Bacteriophage MS2 is an RNA-containing phage with a fairly simple life cycle; Van Duin, J., *Single-Stranded RNA Bacteriophages in The Bacteriophages*, Chapter 4, pgs. 117-167, Plenum Press, New York (1988). The RNA encodes four genes,
20 one of which is a replicase gene that copies the genome, another of which is the multifunctional coat protein gene. As the concentration of the coat protein increases in the cell, it forms a dimer and binds to a hairpin structure consisting of the ribosome binding
25 site and ATG of the replicase gene. This binding then inhibits further translation from the replicase gene and effectively shifts the life cycle to the packaging of the genome.

The sequence of the MS2 coat protein has been
30 published; Fiers et al., *Nature*, 260:500-507 (1976), mutants of the coat protein have been isolated and characterized; Peabody & Ely, *Nucleic Acids Research*, 20(7):1649-1655 (1992), and construction of a two-plasmid system for genetic analysis of the
35 translational repressor activity of coat protein has

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been described; Peabody, D., *Journ. of Biol. Chem.*,
265(10):5684-5689 (1990).

Bacteriophage MS2 is not the only phage known
to have proteins that bind messenger RNA and inhibit
5 translation. For example, the RegA protein of
bacteriophage T4 and the gene V protein of M13 are two
other such proteins. However, a key difference between
the RegA protein, gene V protein, and the MS2 coat
protein relates to the placement of their recognition
10 sites relative to the start site of the gene. For
example, the RegA protein's recognition site is
comprised of sequences in the coding region of the
gene, thus limiting the genes that may be controlled by
it. The gene V protein recognizes a sequence upstream
15 of the ribosome binding sequence and thus may still
allow a low level of translational initiation. For
MS2, the binding site does not cover coding regions of
the gene but does include the ribosome binding sequence
and initiation codon. The MS2 system thus allows for
20 the tightest possible repression, while still allowing
for the site to be used universally.

The specific use of the MS2CP and MS2
recognition site will be described in more detail in
the examples provided herein. As demonstrated by those
25 examples, this unique use of the MS2 system allows one
of ordinary skill in the art to effectively solve the
problem of promoter leakage normally associated with
the expression of heterologous genes in bacteria. From
a commercial production standpoint, this is
30 particularly useful because it is generally not
favorable to be leaking product prior to the induction
point. And, as relates to the ability to effectively
express toxic genes, this can be of tremendous value to
those working in the field, as some of these genes, if
35 expressed in limited quantities, can have beneficial
uses.

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Another important aspect of bacterial expression system design is regulation of transcription. It is known that for many organisms the timing of gene expression is regulated by the production of specific transcription control proteins. This is particularly true for a number of different bacteriophage, as the progression through their life cycle is regulated by the appearance of different transcription proteins that lead to expression of whole classes of genes corresponding to that stage of their development. For example, it has been known for a long time that bacteriophage T4 moved through its life cycle in this way, and the actual mechanisms have recently been elucidated; Brody et al., *FEMS Micro. Letters*, 128:1-8 (1995). This lytic phage has three gene classes: early; middle; and late. The early gene promoters are very similar to strong *E. coli* promoters and are recognized immediately after infection by the host RNA polymerase. The accumulation of two early gene products, motA and asiA, shifts transcription to the middle mode.

The motA protein is a 23.5 kDa protein which guides the RNA polymerase to the T4 middle promoters by recognizing a sequence at the -30 region of the promoters. The asiA protein is a 10.5 kDa protein originally thought to be an anti-sigma factor protein, i.e., that it bound the sigma 70 of *E. coli* and rendered it non-functional. It is now thought, however, that binding of asiA to sigma 70 actually causes a conformational change that abolishes recognition of the -35 region of *E. coli* promoters, and the asiA protein may act as a bridge between the motA protein and the sigma 70 subunit. Moreover, asiA protein also inhibits recognition of T4 early promoters. motA and asiA are necessary and sufficient to specify transcription from T4 middle promoters.

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These details have been determined by *in vitro* transcription assays using purified *motA* and *asiA* and unmodified *E. coli* RNA polymerase; Ouhammouch et al., *Proc. Natl. Acad. Sci. USA*, 92:1451-1455 (1995).

5 The present invention provides a novel and new use of the T4 middle promoters to regulate transcription of any cloned gene in a prokaryotic host cell. The major advantages of this promoter system is that it directs transcription from specific promoters
10 while inhibiting transcription from *E. coli* promoters, which thus minimizes competition for translational apparatus and inhibits the cell from responding to target protein production by inducing transcription of protease genes. Using the T4 middle promoter system
15 described herein, it is also possible to express certain accessory proteins prior to target protein induction in a "staged" expression cycle that can be induced by a single signal, thus reducing the complicated nature of current expression protocols
20 which generally require multiple induction events to accomplish such expression. The specifics of the T4 middle promoter system are described in the examples provided herein.

 The present invention, through its
25 utilization of the MS2 system to tightly regulate translation, and its utilization of T4 middle promoters to regulate transcription, provides highly efficient, tightly regulated expression vector systems capable of expressing exogenous genes, including toxic genes, in
30 *E. coli*, and other host cells. The systems described herein, in addition to addressing the problems associated with other known systems, provide, for the first time, staged promoter systems which are much more versatile than the previously described systems. These
35 systems will be of tremendous value to those working in the area of bacterial expression system design.

SUMMARY OF THE INVENTION

The present invention provides a
5 translational repression system for use in cloning or
expressing a heterologous gene in host cells, said
system comprising a translational repressor operably
linked to a constitutive promoter. In a preferred
embodiment, the translational repressor is MS2 coat
10 protein.

The invention further provides an improved
process for cloning or expressing a heterologous gene,
said process comprising culturing, under suitable
conditions, host cells transformed with a plasmid
15 vector, said vector comprising a DNA sequence encoding
an inducible promoter, a DNA sequence encoding said
heterologous gene linked to a translational repressor
recognition site, and a DNA sequence encoding a
translational repressor operably linked to a
20 constitutive promoter; wherein said translational
repressor controls expression of said heterologous
gene. In a preferred embodiment, the translational
repressor is MS2 coat protein. In one embodiment, the
vector further comprises DNA sequence encoding
25 0.3 - 0.7 early genes of bacteriophage T7 (SEQ ID
NO:2).

The invention further provides an improved
process for cloning or expressing a heterologous gene,
said process comprising culturing, under suitable
30 conditions, host cells which have been co-transformed
with a first plasmid vector comprising a DNA sequence
encoding an inducible promoter and said heterologous
gene linked to a translational repressor recognition
site, and a second plasmid vector comprising a DNA
35 sequence encoding a translational repressor operably
linked to a constitutive promoter; wherein said

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translational repressor controls expression of said heterologous gene. In a preferred embodiment, the translational repressor is MS2 coat protein.

The invention further provides an improved
5 process for cloning or expressing a heterologous gene, said process comprising culturing, under suitable conditions, host cells harboring a DNA sequence encoding a translational repressor operably linked to a constitutive promoter, transformed with a plasmid
10 vector, said vector comprising a DNA sequence encoding an inducible promoter, and a DNA sequence encoding said heterologous gene linked to a translational repressor recognition site; wherein said translational repressor controls expression of said heterologous gene. In a
15 preferred embodiment, the translational repressor is MS2 coat protein.

The invention further provides an improved process for cloning or expressing a heterologous gene, said process comprising culturing, under suitable
20 conditions, host cells harboring a DNA sequence encoding an inducible promoter, a DNA sequence encoding said heterologous gene linked to a translational repressor recognition site, and a DNA sequence encoding a translational repressor operably linked to a
25 constitutive promoter; wherein said translational repressor controls expression of said heterologous gene. In a preferred embodiment, the translational repressor is MS2 coat protein.

The invention further provides an "MS2
30 controlled T7 gene 1 cassette", said cassette comprising a DNA sequence encoding an inducible promoter, the MS2 recognition site linked to T7 gene 1, and the MS2 coat protein gene under the control of a weak constitutive promoter.

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The invention further provides host cells capable of expressing a heterologous gene and harboring an "MS2 controlled T7 gene 1 cassette".

5 The invention further provides an improved process for expressing a heterologous gene, said process comprising culturing, under suitable conditions, host cells harboring an "MS2 controlled T7 gene 1 cassette" and transformed with an expression vector containing a DNA sequence encoding said
10 heterologous gene under the control of a T7 promoter.

The invention further provides a series of host cells capable of cloning or expressing a heterologous gene, said host cells engineered to produce different concentrations of MS2CP.

15 The invention further provides a staged inducible promoter system for cloning or expressing a heterologous gene, said system comprising regulated transcriptional control proteins that direct transcription from specific promoters, while inhibiting
20 general transcription from bacterial host promoters. In a preferred embodiment, the transcriptional control proteins are motA and asiA, and said proteins are regulated by MS2CP.

The invention further provides an improved
25 process for cloning or expressing a heterologous gene, said process comprising culturing, under suitable conditions, host cells which have been co-transformed with a first plasmid vector comprising a DNA sequence encoding said heterologous gene under the control of T4
30 middle promoter, and a second plasmid vector comprising a DNA sequence encoding an inducible promoter, motA and asiA gene sequences each linked to a translational repressor recognition site, and a translational repressor operably linked to a constitutive promoter;
35 wherein said translational repressor controls expression of said motA and asiA genes, and wherein

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said *motA* and *asiA* genes direct transcription from the T4 middle promoter while inhibiting transcription from said inducible promoter. In a preferred embodiment, the translational repressor is MS2 coat protein. In
5 one embodiment, the second plasmid vector further comprises a DNA sequence encoding an accessory protein.

The invention further provides an improved process for cloning or expressing a heterologous gene, said process comprising culturing, under suitable
10 conditions, host cells harboring a DNA sequence encoding an inducible promoter, *motA* and *asiA* gene sequences each linked to a translational repressor recognition site, and a translational repressor operably linked to a constitutive promoter, transformed
15 with a plasmid vector comprising a DNA sequence encoding said heterologous gene linked under the control of T4 middle promoter; wherein said translational repressor controls expression of said
20 *motA* and *asiA* genes, and wherein said *motA* and *asiA* genes direct transcription from the T4 middle promoter while inhibiting transcription from said inducible promoter. In a preferred embodiment, the translational repressor is MS2 coat protein.

The invention further provides an "MS2-based
25 T4 cassette", said cassette comprising a DNA sequence encoding an inducible promoter, *motA* and *asiA* gene sequences each linked to an MS2 recognition sequence, and the MS2 coat protein gene under the control of a constitutive promoter.

30 The invention further provides a prokaryotic host cell capable of expressing a heterologous gene and harboring an "MS2-based T4 cassette".

The invention further provides an improved process for cloning or expressing a heterologous gene,
35 said process comprising culturing, under suitable conditions, host cells harboring an "MS2-based

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cassette" and transformed with an expression vector containing a DNA sequence encoding said heterologous gene under the control of a T4 promoter.

The invention further provides the DNA
5 sequence of SEQ ID NO:1 and the DNA sequence of SEQ ID NO:2.

BRIEF DESCRIPTION OF THE DRAWINGS

10 Figure 1 is the complete gene sequence (SEQ ID NO:1) of the wildtype MS2 coat protein used in the systems of the present invention. The gene has a NdeI site at the 5' end, and a BamHI site at the 3' end.

15 Figure 2 is a photograph of an SDS gel showing the results of the wtMS2CP expression experiments. Lane 1 is an uninduced putative positive clone from BL21(DE3) host cells (containing the wtMS2CP
20 gene in pT7-7) grown to an O.D. of 0.6; Lanes 2-14 are various putative positive clones from BL21(DE3) host cells (containing the wtMS2CP gene in pT7-7) after 4 hours of induction at 37°C. Lane 15 is the low range Amersham rainbow markers.

25 Figure 3 is a schematic diagram of the pRIN plasmid vectors developed in the present invention.

30 Figure 4 is a photograph of a western blot showing the results of an expression and leakage experiment carried out with various pRIN plasmid vectors into which the T7 gene 1 had been cloned. This particular blot is of an overnight stationary culture, and each set of lanes is T7 gene 1, plus or minus (m) a
35 downstream box, in the same vector. The first three

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sets of lanes use pRIN11 (PS4 promoter) with various MS2CPs. The last three sets of lanes use pRIN20 (UV5 lac promoter) with various MS2CPs. Lane 4 is the low range Biorad molecular weight marker.

5

Figure 5 is a photograph of a western blot showing the results of an expression and leakage experiment carried out with various pRIN plasmid vectors into which the T7 gene 1 had been cloned. This particular blot is of an exponentially growing preinduction culture (preI), and each set of lanes is T7 gene 1, plus or minus (m) a downstream box, in the same vector. The first three sets of lanes use pRIN11 (PS4 promoter) with various MS2CPs. The last three sets of lanes use pRIN20 (UV5 lac promoter) with various MS2CPs. Lane 1 is the low range Biorad molecular weight marker.

Figure 6 is a photograph of a western blot showing the results of an expression and leakage experiment carried out with various pRIN plasmid vectors into which the T7 gene 1 had been cloned. This particular blot is of an IPTG induced culture grown at 28°C, and each set of lanes is a downstream box plus or minus (m) gene 1 in the same vector. The first three sets of lanes use pRIN11 (PS4 promoter) with various MS2CPs. The last three sets of lanes use pRIN20 (UV5 lac promoter) with various MS2CPs. Lane 2 is the low range Biorad molecular weight marker.

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Figure 7 is a schematic diagram of a "MS2 controlled T7 gene 1 cassette".

Figure 8 is a picture of an SDS gel which compares the leakage and expression characteristics of

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the commercially available BL21(DE3) strain (lanes 3-5), the BL21(DE3) strain containing pLysS as a secondary vector (lanes 1-2), the EE11-20 strain (lanes 6-8), and the EE11-20 strain containing pLysS as a secondary vector (lanes 9-10). Comparisons were based on expression of NT-3 as the target product gene. Lanes 1, 5, 6 and 10 represent overnight (ON) cultures, lanes 4 and 7 represent preinduction (preI) cultures, and lanes 2, 3, 8 and 9 represent induction (using IPTG at 28°C) (I-28) cultures.

Figure 9 is a picture of an SDS gel which compares the leakage and expression characteristics of the commercially available BL21(DE3) strain (lanes 3-5), the BL21(DE3) strain containing pLysS as a secondary vector (lanes 1-2), the EE11-20 strain (lanes 6-8), and the EE11-20 strain containing pLysS as a secondary vector (lanes 9-10). Comparisons were based on expression of BDNF as the target product gene. Lanes 1, 5, 6 and 10 represent overnight (ON) cultures, lanes 4 and 7 represent preinduction (preI) cultures, and lanes 2, 3, 8 and 9 represent induction (using IPTG at 28°C) (I-28) cultures.

Figure 10 is a picture of an SDS gel which compares the leakage and expression characteristics of the commercially available BL21(DE3) strain (lanes 3-5), the BL21(DE3) strain containing pLysS as a secondary vector (lanes 1-2), the EE11-20 strain (lanes 6-8), and the EE11-20 strain containing pLysS as a secondary vector (lanes 9-10). Comparisons were based on expression of BDNF as the target product gene. Lanes 1, 5, 6 and 10 represent overnight (ON) cultures, lanes 4 and 7 represent preinduction (preI) cultures,

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and lanes 2, 3, 8 and 9 represent induction (using IPTG at 28°C) (I-28) cultures.

Figure 11 is a picture of an SDS gel which compares the leakage and expression characteristics of the commercially available BL21(DE3) strain (lanes 5-7), and the EE11-11M strain (lanes 2-4). Comparisons were based on expression of BDNF as the target product gene. Lanes 4 and 5 represent overnight (ON) cultures, lanes 3 and 7 represent preinduction (preI) cultures, and lanes 2 and 6 represent induction (using IPTG at 28°C) (I-28) cultures. Lane 1 is the low range Biorad molecular weight marker.

Figure 12 is a picture of an SDS gel which shows the leakage and expression characteristics of the EE11-11M strain using expression of NT-3 as the target product gene. Lane 5 represents overnight (ON) culture, lane 4 represents preinduction (preI) cultures, and lanes 2 and 3 represent induction using IPTG at 28°C (I-28) or IPTG at 37°C (I-37) cultures. Lane 1 is the low range Biorad molecular weight marker.

Figure 13 is a picture of an SDS gel which shows a 10 liter fermentation induction time course of GCSF in pAMG25 in strain EE11-11M. Lane 1 is the culture at the time of induction. Lane 2 is the culture at the time of induction. Lanes 3-9 are the culture after additional hours of growth in the presence of inducer (IPTG), e.g., lane 3 is after 1 hour, lane 4 is after 2 hours, etc. Lane 10 is Amersham low molecular weight rainbow markers. The last lane is a GCSF marker.

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Figure 14 is a picture of an SDS gel which shows a 10 liter fermentation induction time course of leptin in pAMG25 in strain EE11-11M. Lane 1 is Amersham low molecular weight rainbow markers. Lane 2 is the culture at the time of induction. Lanes 3-8 are the culture after additional hours of growth in the presence of inducer (IPTG), e.g., lane 3 is after 1 hour, lane 4 is after 2 hours, etc. Lane 9 is a leptin marker.

10

Figure 15 is a photograph of a western blot showing the results of an expression experiment carried out using an MS2 based system into which the 0.4 early gene of T7 had been cloned. Lanes 2, 4, 6 and 8 represent four different 0.4 containing cultures after 4 hours of induction at 42°C; Lanes 3, 5, 7 and 9 are the uninduced samples of the same cultures. Lane 1 is the low range Biorad molecular weight marker.

15

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Figure 16 is a photograph of an SDS gel showing the results of an expression experiment carried out using an MS2 based system into which the 0.6 early gene of T7 had been cloned. Lanes 2 and 4 represent two different 0.6 containing cultures uninduced; Lanes 3 and 5 are the same samples after 4 hours of induction at 42°C. Lane 1 is the low range Biorad molecular weight marker.

25

Figure 17 is the complete gene sequence (SEQ ID NO:2) of the 3-7t operon constructed to contain the early genes (0.3-0.7) of T7.

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Figure 18 is a picture of an SDS gel which compares the expression of NDF alpha/beta in the absence and presence of the T7 early proteins. The

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3-7t operon was in pRIN 10 and was induced by a shift in temperature from 28°C to 37°C. NDF alpha/beta was in plasmid pAMG33 and is induced by the addition of IPTG when the temperature is shifted back to 28°C. The left half of the gel is a time course of NDF alpha/beta in the absence of the T7 early genes. Lane 1 is after induction of the early proteins but prior to induction of NDF alpha/beta. Lanes 2-4 are the culture after additional hours of growth in the presence of inducer (IPTG), e.g., lane 2 is after 1 hour, lane 3 is after 2 hours, etc. Lane 5 is Amersham low molecular weight rainbow markers. The right half of the gel is a time course of NDF alpha/beta expression in the presence of the T7 early proteins. Lane 6 is after induction of the early proteins but prior to induction of NDF alpha/beta. Lanes 7-9 are the culture after an additional hour of growth in the presence of inducer (IPTG).

Figure 19 is a picture of a western blot of a gel comparing the expression of a truncated version of human telomerase subunit TP2 (301-941 TP2) in the presence and absence of T7 early proteins. The 3-7t operon was in pRIN10 and was induced by a shift in temperature from 28°C to 37°C. 301-941 TP2 was in plasmid pAMG22 and is induced by the addition of IPTG when the temperature is shifted back to 28°C. Lane 1 is a preinduction sample from 301-941 TP2 in the presence of the T7 early proteins. Lane 2 is the expression of 301-941 TP2 after 2 hours of induction in the presence of T7 early proteins at 28°C. Lane 3 is the expression of 301-941 TP2 after 2 hours of induction in the presence of T7 early proteins at 37°C. Lane 4 lane is a preinduction sample from 301-941 TP2 in the absence of the T7 early proteins. Lane 5 is the

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expression of 301-941 TP2 after 2 hours of induction in the absence of T7 early proteins at 37°C.

Figure 20 is a picture of a western blot of a gel showing the passive production of varying levels of MS2 coat protein by strains GM315, GM320, GM340 and GM350. The strains are compared against the parent strain from which they were constructed. Lane 1 represents a log phase culture of GM315. Lanes 2, 4, 6, 8 and 10 are parent strain 393. Lanes 3 and 5 are GM320, lane 7 is GM340, and lane 9 is GM350.

Figure 21 is a picture of a gel showing the expression of the Hepatitis C polymerase (HepCpol) in strains having varying levels of MS2 coat protein (the soluble and insoluble fractions from each expression experiment are also compared). Lane 1 is molecular weight markers. Lane 2 is whole cell extract of an induced culture of HepCpol in pAMG21 expressed in strain GM221 which contains no MS2 coat protein. Lane 3 is the insoluble fraction from this experiment and lane 4 is the soluble fraction. Lane 5 is whole cell extract of an induced culture of HepCpol in pAMG21 expressed in strain GM315 which contains MS2 coat protein. Lane 6 is the insoluble fraction from this experiment and lane 7 is the soluble fraction. Lane 8 is whole cell extract of an induced culture of HepC in pAMG21 expressed in strain GM320 which contains more MS2 coat protein than that in GM315. Lane 9 is the insoluble fraction from this experiment and lane 10 is the soluble fraction.

Figure 22 is the complete DNA sequence (SEQ ID NO:3) of the T4 PuvsX middle promoter used in the systems of the present invention. The gene has a

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AatII site at the 5' end, and a ClaI site at the 3' end.

Figure 23 is the complete DNA sequence (SEQ ID NO:4) of the T4 PX middle promoter used in the systems of the present invention. The gene has a AatII site at the 5' end, and a ClaI site at the 3' end.

Figure 24 is a picture of an SDS gel which shows the leakage and expression characteristics of pAMG13 using expression of T7 gene 1 (under the control of a lambda promoter) as the target product gene. Lane 5 represents a stationary sample which grew overnight at 28°C, lane 4 represents a sample which was induced for 4 hours at 42°C, lane 3 represents a sample which was induced for 4 hours at 37°C, lane 2 represents an uninduced sample which grew at 28°C to an O.D. of 0.6, and lane 1 is the low range Biorad molecular weight marker.

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Figure 25 is a picture of an SDS gel which shows the leakage and expression characteristics of pAMG13 in which T7 gene 1 was coexpressed with T4 operon pRIN10. Lane 4 represents a stationary sample which grew overnight at 28°C, lane 3 represents a sample which was induced for 4 hours at 42°C, lane 2 represents a sample which was induced for 4 hours at 37°C, and lane 1 represents an uninduced sample which grew at 28°C to an O.D. of 0.6.

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Figure 26 is a picture of an SDS gel which shows the leakage and expression characteristics of pAMGuvsX in which T7 gene 1 (under the control of the uvsX T4 middle promoter) was coexpressed with T4 operon

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pRIN10. Lane 4 represents a stationary sample which grew overnight at 28°C, lane 3 represents a sample which was induced for 4 hours at 42°C, lane 2 represents a sample which was induced for 4 hours at 37°C, and lane 1 represents an uninduced sample which grew at 28°C to an O.D. of 0.6.

Figure 27 is a picture of an SDS gel which shows the leakage and expression characteristics of pAMGuvsX in which T7 gene 1 was coexpressed with T4 operon pRIN11. Lane 5 represents a stationary sample which grew overnight at 28°C, lane 4 represents a sample which was induced for 4 hours at 37°C, lane 3 represents a sample which was induced for 4 hours at 28°C, lane 2 represents an uninduced sample which grew at 28°C to an O.D. of 0.6, and lane 1 is the low range Biorad molecular weight marker.

Figure 28 is a picture of an SDS gel which shows the leakage and expression characteristics of pAMGuvsX in which NT-3 (under the control of the uvsX T4 middle promoter) was coexpressed with T4 operon pRIN10. Lane 4 represents a sample which was induced for 4 hours at 42°C, lane 3 represents a sample which was induced for 4 hours at 37°C, lane 2 represents an uninduced sample which grew at 28°C to an O.D. of 0.6, and lane 1 is the low range Biorad molecular weight marker.

Figure 29 is a picture of an SDS gel which shows the leakage and expression characteristics of pAMGuvsX in which BDNF (under the control of the uvsX T4 middle promoter) was coexpressed with T4 operon

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pRIN10. Lane 5 represents a sample which was induced for 4 hours at 42°C, lane 4 represents a sample which was induced for 4 hours at 37°C, lane 3 represents a sample which was induced for 4 hours at 28°C, lane 2 represents an uninduced sample which grew at 28°C to an O.D. of 0.6, and lane 1 is the low range Biorad molecular weight marker.

Figure 30 is a schematic diagram of the pCB plasmid vectors developed in the present invention.

Figure 31 is a schematic diagram of the pAW plasmid vectors developed in the present invention.

Figure 32 is a picture of an SDS gel which shows the leakage and expression characteristics of pAMGX in which T7 gene 1 (under the control of the T4 X middle promoter) was coexpressed with pAW20. Lane 4 represents a stationary sample which grew overnight at overnight 28°C, lane 3 represents a sample which was induced for 4 hours at 28°C, lane 2 represents an uninduced sample which grew at 28°C to an O.D. of 0.6, and lane 1 is the low range Biorad molecular weight marker.

Figure 33 is a picture of an SDS gel which shows the leakage and expression characteristics of pAMGX in which SPI (under the control of the T4 X middle promoter) was coexpressed with pAW20. Lane 3 represents a sample which was induced for 4 hours at 28°C, lane 2 represents an uninduced sample which grew at 28°C to an O.D. of 0.6, and lane 1 is the low range Biorad molecular weight marker.

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Figure 34 is a picture of an SDS gel which shows the leakage and expression characteristics of pAMGuvsX in which OPG (under the control of the T4 uvsX middle promoter) was coexpressed with pAW20. Lane 4 represents a sample which was induced for 4 hours at 28°C, lane 2 represents an uninduced sample which grew at 28°C to an O.D. of 0.6, and lane 1 is the low range Biorad molecular weight marker.

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Figure 35 is a picture of an SDS gel which shows leakage and expression characteristics of pAMGuvsX in which BDNF (under the control of the T4 uvsX middle promoter) was coexpressed with pAW11. Lane 1 represents an uninduced sample, lane 2 represents a sample induced at 28°C for 4 hours and lane 3 represents a sample induced at 37°C for 4 hours.

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Figure 36 is a picture of an SDS gel which shows leakage and expression characteristics of pAMGuvsX in which OPG (under the control of the T4 uvsX middle promoter) was coexpressed with pAW11. Lane 1 lane is Amersham low molecular weight rainbow markers, Lane 2 represents an uninduced sample, lane 3 represents a sample induced at 28°C for 4 hours and lane 4 represents a sample induced at 37°C for 4 hours.

20

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Figure 37 is a picture of an SDS gel which shows leakage and expression characteristics of pAMGuvsX in which NT3 (under the control of the T4 uvsX middle promoter) was coexpressed with pAW11. Lane 1 represents an uninduced sample, lane 2 represents a sample induced at 28°C for 4 hours and lane 3 represents a sample induced at 37°C for 4 hours.

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Figure 38 is a picture of an SDS gel which shows leakage and expression characteristics of pAMGX in which 3MNDF (under the control of the T4 X middle promoter) was coexpressed with pAW11. Lane 1 represents an uninduced sample, lane 2 represents a sample induced at 28°C for 4 hours and lane 3 represents a sample induced at 37°C for 4 hours.

Figure 39 is a picture of an SDS gel which shows the leakage and expression characteristics of pAMGuvsX in which BDNF (under the control of the T4 uvsX middle promoter) was coexpressed with a T4 operon pRIN10 which also contained 0.6 gene as an accessory protein. Lane 5 represents a sample which was induced for 4 hours at 42°C, lane 4 represents a sample which was induced for 4 hours at 37°C, lane 3 represents a sample which was induced for 4 hours at 28°C, lane 2 represents an uninduced sample which grew at 28°C to an O.D. of 0.6, and lane 1 is the low range Biorad molecular weight marker.

DETAILED DESCRIPTION OF THE INVENTION

For purposes of the present invention, a "translational repressor" is defined as protein capable of specifically binding a recognition site on a piece of RNA and inhibiting translation. In the present invention, the MS2 coat protein and MS2 recognition site are used to provide a translational repressor system. Briefly, the published sequence of the MS2CP was used to generate oligonucleotides from which the intact gene was constructed. Then, after determining that MS2CP was tolerated at very high levels in *E. coli* without any apparent effect on cell growth, MS2CP was placed under the control of a weak constitutive

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promoter in plasmids of varying copy number. The idea was to continuously produce low levels of MS2CP so that any cloned genes which have an MS2 recognition site may be kept completely silent until it is useful to express them.

Using this approach, it was demonstrated that this MS2-based system could be used to provide an improved, tightly controlled system involving, e.g., the T7 RNA polymerase gene. Cloned T7 gene 1 provides a source of T7 RNA polymerase for directing selective, high-level expression of target genes under the control of a T7 promoter. However, because T7 RNA polymerase is so active and selective, it is important to control basal levels of active T7 RNA polymerase, i.e. shut off T7 gene 1 in the uninduced state, so as to prevent premature expression of the target gene.

The strategy utilized in the present invention thus involved the cloning of the T7 gene 1 with an MS2 recognition site linked to its coding sequence, and the insertion of this construct into the chromosome along with a copy of the MS2 coat protein under the control of a weak constitutive promoter. The two genes were cloned tail to tail such that the promoters for each were oriented in opposing directions. It was then demonstrated that host cells containing a chromosomal copy of this "MS2 controlled T7 gene 1" construct allowed for effective production of T7 RNA polymerase which could then be used to drive expression of a target gene.

Target genes successfully tested in the system of the present invention included T7 gene 1, neurotrophic factor-3 (NT-3), brain-derived neurotrophic factor (BDNF), serine protease inhibitor (SPI) and osteoprotegerin (OPG), neu differentiation factor (NDF) alpha/beta, hepatitis C polymerase, human telomerase, and analogs, derivatives and variants thereof. It is contemplated that the various MS2 controlled systems can provide improved control for any

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cloned gene, toxic or nontoxic, in a prokaryotic host cell.

It was further demonstrated that the MS2-based system could be used to stably clone and express certain toxic genes. As used herein, a toxic gene is any gene whose expression in the host cell will prevent the host cell in culture from achieving the normal logarithmic growth it would have achieved but for the expression of the toxic gene. As examples in the present invention, the early genes of bacteriophage T7 were cloned and expressed, as were *motA* and *asiA*. Several of the early genes of bacteriophage T7 are known to be toxic; Studier and Rosenberg, *J. Mol. Biol.*, 153:503-525 (1981). The 0.7 gene, in particular, is lethal as it encodes a function that inhibits *E. coli* RNA polymerase. *motA* and *asiA* are also now known to be toxic; Hinton et al., *Methods in Enzymol.*, 274:43-57 (1996). The ability to express such genes is of significant value because some of these genes have also been shown to have a positive effect on heterologous gene expression in *E. coli* by phage infection. In other words, there are times when it is useful to have a cloned copy of these genes present in the cell for expression just prior to the expression of the target gene.

In the examples provided herein, the T7 gene 1 was under the control of the UV5 lac promoter; Fuller, F., *Gene*, 19:43-54 (1982), the PS4 promoter; WO 95/267246 (Bartley et al.), published October 12, 1995, and the lux promoter; U.S. Patent No. 5,196,318 (Baldwin et al.), issued March 23, 1993. Importantly, however, the T7 gene 1 could have been under the control of any inducible promoter, including bacterial promoters such as *trp*-, or *lpp*-; phage promoters such as a lambda P_L or P_R ; or synthetic promoters such as *tac* or *trc*.

Also developed and described herein as effective in the system of the present invention are mutant forms of the MS2CP. For example, a mutant

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version of the MS2CP in which the codon for the valine residue at position 29 has been changed to a codon for isoleucine was constructed. This mutation effects the ability of coat protein dimers to associate into capsid size aggregates; Peabody, D.S. and Ely, R., *Nuc. Acid Res.*, 20(7):1649-1655 (1992). Because the coat protein binds to its mRNA target as a dimer and multimerization of dimers is thought to inhibit association with the mRNA, this mutation would thus be expected to increase the effective concentration of translational repressors present without increasing the actual protein concentration by keeping more coat protein in dimers rather than multimers. It would be understood by those of ordinary skill in the art that other mutant forms of the MS2CP would be effective in the systems of the present invention.

Although the examples provided herein specifically utilize the bacteriophage MS2 system, it would not be unexpected that other similar systems, e.g., Q β , GA, SP, R17, f2 and fr, could be used as translational repressor systems in a similar manner.

Host cells used and evaluated in the present invention included the *E. coli* B strain BL21(DE3) \pm pLysS and the *E. coli* K strain EE1120 \pm pLysS. It would clearly be understood by one of ordinary skill in the art that other commonly used *E. coli* B strains and K strains would be effective in the practice of the present invention. It would also be understood that various eukaryotic host cells could be utilized in the practice of the present invention.

Strong transcriptional terminators are also utilized in the systems of the present invention. By inserting such terminators upstream of the promoter of interest (e.g. the promoter directing expression of the T7 gene 1), read-through transcription from cryptic

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promoter sequences is eliminated, thus providing a more tightly regulated system. T1T2 terminators; Amman et al., *Gene*, 25:167-178 (1983) were used in the examples of the present invention; however, there are other strong terminators, e.g., t_{HP} ; Nohno et al., *Mol. Gen. Genet.*, 205:260-269 (1986) that would clearly be expected to work effectively in the system of the present invention.

Although T7 RNA polymerase was used in the examples of the present invention, equivalent RNA polymerases from T7-like phages would also work. Such phages are described in detail in the art; see e.g., Hausmann, R., *The T7 Group in The Bacteriophages*, Chapter 8, pgs. 259-283, Plenum Press, New York (1988).

Also described in the present invention is the construction of a system for the activation of a cloned T4 middle promoter *in vivo* using a specially constructed operon consisting of *motA* and *asiA* genes under the control of an inducible promoter. The major advantage of this promoter system is that it directs transcription from specific promoters while inhibiting transcription from *E. coli* promoters, which minimizes competition for translational apparatus and inhibits the cell from responding to target protein production by inducing transcription of protease genes. It was also demonstrated that the system would provide a "staged" expression cycle that could be useful for, *inter alia*, expressing certain accessory proteins that may be helpful to the production of the target protein.

More specifically, the idea was that the accessory proteins could be cloned under a promoter that is induced in the same way as the *motA* and *asiA* promoter, or they could all be under the control of the same promoter in a single operon conformation. When the induction signal is given these accessory proteins and *motA* and *asiA* would be produced simultaneously.

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When *motA* and *asiA* reached saturating levels (equal to or somewhat higher than the number of RNA polymerase molecules present) then transcription from *E. coli* promoters would be inhibited, ending that stage of the expression cycle. The RNA polymerase would then be directed solely to T4 middle promoters which would lead to the expression of the target protein. There is currently no system available which can do this in *E. coli*.

The ability to express such accessory proteins in this manner can be of great benefit in improving expression of proteins in prokaryotic systems. For example, Yasukawa et al., *The Journ. of Biol. Chem.*, 270(432):25328-25331 (1995) reported that coproduction of the *E. coli* thioredoxin (Trx) or *E. coli* chaperones GroESL, increased the solubilities of various vertebrate proteins being produced in *E. coli* (Trx was most effective). This is an important and useful finding because eukaryotic proteins are frequently produced in *E. coli* as insoluble aggregates, and this is one of the barriers to studies of macromolecular structure.

In the present invention, the *motA* and *asiA* genes have been cloned under the lambda P_L promoter and also cloned under a lac derived promoter. Importantly, however, any inducible promoter would work, including bacterial promoters such as *trp*-, or *lpp*-; phage promoters such as lambda P_L or P_R ; or synthetic promoters such as *tac* or *trc*.

Because the T4 middle promoters were found to be "leaky", and, more importantly, because the toxic genes *motA* and *asiA* need to be carefully controlled, the features of the MS2 system and the T4 middle promoter system were combined. *motA/asiA* operons were found to be unclonable unless both genes were linked to an MS2 recognition site. Optimal "MS2-based T4

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cassettes" to be inserted into the host cell chromosome thus contain a *motA*-*asiA* inducible promoter with *motA* and *asiA* gene sequences (\pm accessory protein sequence) linked to an MS2 coat protein recognition sequence, and
5 a MS2 coat protein gene operably linked to a weak constitutive promoter.

Utilizing this system, the low level production of MS2CP prevents T4 middle promoter leakage and *motA/asiA* production until an induction event
10 occurs which then drives *motA/asiA* production (and accessory protein production, if intended) and shuts down *E. coli* transcription, followed by production of the target gene driven by T4 middle promoters.

Also developed and described herein are a series of *E. coli* strains which have been engineered to produce different concentrations of MS2CP. These strains have had the MS2 coat protein under the control of modified TET promoter sequences integrated into their chromosomal DNA at specific sites. The TET
15 promoter sequences were modified by changing bases in the -10 and -35 regions to make them homologous with consensus sequence for these regions in strong *E. coli* promoters. They have also been altered by using oligonucleotides to randomize the sequence of the
20 ribosome binding site. These changes allowed for the identification of a number of forms that produce higher levels of MS2 coat protein as determined by western analysis.

The various MS2-containing strains of the present invention can be utilized to clone toxic and
30 other genes which cannot be cloned using conventional technology. For example, it has been determined that, when working with toxic genes, the establishment of the initial ligation is the step most sensitive to the
35 toxicity and thus the most difficult step in the cloning process. Once a stable clone has been isolated

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however, it can then be transformed into other cell lines without incident. Using GM350, one could couple the toxic or "unclonable" gene to an MS2 recognition site and then use the ligation to transform GM350.

5 Because GM350 has the highest production of MS2 coat protein; in fact, so much MS2CP is produced that expression upon induction is effectively eliminated, GM350 can be used to identify and obtain a stable clone. Once the stable clone has been obtained and
10 sequence confirmed, the recombinant plasmid can be used to transform the other MS2 strains which produce decreasing amount of coat protein. The stability of the clone in each strain could be determined and the protein ultimately expressed in one such strain. In
15 cases where toxicity persists subsequent to obtaining the initial clone, the low level MS2CP producers, e.g., GM315 and GM320 would be useful in stabilizing those constructs.

20 The following examples are offered to more fully illustrate the invention, but are not to be construed as limiting the scope thereof. Example 1 describes the construction of the wildtype MS2 coat (wtMS2CP) protein gene and then provides the results of
25 testing of the wtMS2CP for its ability to be expressed in *E. coli*, and any effects that such expression had on cell growth. Example 2 describes the construction of two mutant versions of the MS2 coat protein gene. Example 3 describes the construction of the pRIN
30 plasmid vectors containing wtMS2CP or MS2CP mutants for use in the development of the translational repression system. Example 4 describes the cloning of the T7 gene 1 into pRIN plasmid vectors, and the subsequent testing of the vectors for expression and system leakage.
35 Example 5 describes the chromosomal insertion of "MS2 controlled T7 gene 1 cassettes" into the chromosome of

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designed using the TET promoter sequence native to pACYC184 with the alteration of the introduction of an NdeI site at the natural start of the TET gene. The promoter was put into the construct from SacI to NdeI
5 such that the wtMS2CP gene was operably linked to the TET promoter.

A DNA fragment containing the rrnB T1T2 terminator sequences was constructed by PCR using plasmid pKK223-3; Amman et al., *Gene*, 25:167-178 (1983)
10 as a template and using oligonucleotides 1036-6 and 1053-71 (See Table 1). This fragment was constructed to have sites for restriction enzymes AatII and AvaI at the ends. The pACYC184-derived vector described above was cut with these enzymes and this fragment was
15 ligated in.

A synthetic version of a lambda promoter and the multiple cloning site from vector pAMG13 were cut out from AatII to BamHI. The pACYC184-derived vector described was then cut with these enzymes and the
20 fragment from pAMG13 ligated in. The resulting plasmid was named pRIN10(wt) (Figure 3). Three similar pACYC184-derived plasmids, one containing the PS4 promoter instead of the lambda promoter (named pRIN11(wt)), one which contained the UV5 lac promoter
25 instead of the lambda promoter (named pRIN20(wt)), and one which contained the lux promoter (named pRIN22(wt)) were also constructed (Figure 3).

pRIN constructions containing the MS2CP-11 and MS2CP-14 mutants were also constructed. Fragments
30 of the mutant forms, still linked with the TET promoter, were generated so as to have a SphI site at the promoter end, and a BamHI at the end of the MS2CP mutant gene. The pRIN plasmids described above were cut with BamHI and SphI and the plasmid portion was gel
35 purified away from the wtMS2CP fragment. The mutant fragments were then ligated in using the SphI and BamHI

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sites. The constructions containing the MS2CP-11 mutant were named pRIN10(11), pRIN11(11), pRIN20(11), and pRIN22(11), and the constructions containing the MS2CP-14 mutant were named pRIN10(14), pRIN11(14),
5 pRIN20(14) and pRIN22(14).

Example 4

This example describes the cloning of the T7
10 gene 1 into various pRIN plasmid vectors, and the subsequent testing of the plasmid vectors for expression and system leakage.

The T7 gene 1 was cloned into the various pRIN plasmids described above. The T7 gene 1 gene was
15 PCR constructed using oligonucleotides 949-1 and 949-2 (See Table 1) to have an MS2 coat protein recognition sequence linked to its coding sequence. The template used was plasmid pGP1-2; Tabor and Richardson, *Proc. Natl. Acad. Sci. USA*, 82:1074-1078 (1985). The gene
20 was cloned into the various pRIN plasmids from XbaI to BamHI. The MS2CP mutants were tested for their ability to inhibit multimerization and thus lead to an increase in the effective concentration of translational repressor. Another parameter that was examined was the
25 presence or absence of a downstream box sequence in gene 1 (oligonucleotide 1477-84) (See Table 1) (this sequence has been shown to enhance translation by increasing binding to the ribosome; Sprengart et al., *Nuc. Acids Res.*, 18(7):1719-1723 (1990)).

30 Overnight cultures of the various constructs were grown in 5 ml of LB-cam in 50 ml tubes at 28°C. These were used to inoculate fresh 5 ml portions of LB-cam in 15 ml tubes at 1:100 dilution. These were all returned to a 28°C shaker. Samples were taken of
35 the cultures just prior to induction, and the induction step in this case involved the addition of IPTG to a

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final concentration of 0.4mM. Incubation of induced cultures was continued for 3 hours and 1 ml samples were taken. All samples were pelleted by centrifugation and the pellets were resuspended in cracking buffer. After boiling for 5 minutes, a 6 μ l aliquot of each was run on a 4-20% SDS polyacrylamide gel (Novex).

Protein was then electrophoretically transferred to nitrocellulose. The blots were blocked overnight in blotto-tween with 2% non-fat dry milk; Harlow & Lane, *Immunoblotting in Antibodies*, A Laboratory Manual, Chapter 12, Cold Spring Harbor Laboratory Press, (1988). The blots were probed for 1 hour with a rabbit derived polyclonal antibody to T7 RNA polymerase. After washing the blots were probed with donkey anti-rabbit horse radish peroxidase conjugated antibody (Amersham) for 1 hour. This was washed and treated with ECL reagents (Amersham) and exposed to X-ray film. The exposure was for 15 minutes to maximize sensitivity. The film was developed using a Kodak film processor.

Figures 4 - 6 are photographs of western blots showing the results of leakage and expression experiments carried out with various constructs. Figure 4 is a blot of an overnight stationary culture, Figure 5 is a blot of an exponentially growing preinduction culture (preI) and Figure 6 is a blot of an IPTG induced culture grown at 28°C. As evidenced by the pictures of the blots, it is clear the presence of the coat protein has a dramatic effect on overnight leakage (compare Figure 4 and 5), and there is some reduction of the level of protein accumulation in the cells that show the greatest control of leakage. More specifically, the signal is stronger on the left side lanes of the blots and decreases in the right side

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lanes as a function of the tightness and degree of control exercised by the corresponding systems; the PS4 promoter is leakier than the UV5 lac promoter; the mutation of the downstream box lowers leakage, but
5 has little impact on induction level for the PS4 promoter; the MS2CP mutants display tighter control of T7 gene 1 leakage in overnight and exponential cultures than does wildtype; the mutants impact the level of accumulation upon induction, with the more tightly
10 controlled overnight cultures (UV5 lac) displaying lower levels of RNA polymerase after induction; and the MS2CP14 mutant appears to have a greater effect than the MS2CP11 mutant, which is intermediate between wtMS2CP and MS2CP14.

15

Example 5

This example describes the chromosomal insertion of "MS2 controlled T7 gene 1 cassettes" into
20 the chromosome of a host cell, and then demonstrates the use of such host strains to express various target genes as well as providing the results of tests wherein the leakage and expression characteristics of the newly developed strains are compared to commercially
25 available T7 RNA polymerase containing strains.

A "MS2 controlled T7 gene 1 cassette" (contains the upstream terminator sequences, an inducible promoter sequence, the MS2 recognition site, the T7 gene 1, the MS2 coat protein gene (wtMS2CP, or
30 MS2CP-11 or MS2CP-14) and a weak constitutive promoter, e.g., TET) (See Figure 7) was cut out of the various pRIN plasmids using restriction enzymes SphI and PpuMI, and then cloned into a specially constructed M13 vector, MMEbg; Blum et al., *J. Bacteriology*,
35 171(1):538-546 (1889); Micheals, M.L., *Gene*, 93:1-7 (1990) for site specific integration into the host

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chromosome. Various cassettes containing either wtMS2CP, MS2CP-11, or MS2CP-14 were obtained.

The integration proceeds through a forced recombination mechanism. First, oligonucleotides
5 1553-73 and 1553-74 (See Table 1) were ligated into the BamHI and NotI sites of MMeBg. These oligonucleotides introduce unique SphI and PpuMI sites into the vector. The "MS2 controlled T7 gene 1 cassette" was then
10 ligated into the SphI and PpuMI sites. Ligations were then transformed into XL1 Blue cells by putting the cells into 1 ml SOC and plating 150 µl of MOCK ligation and 150 µl and 30 µl of insert ligations with 300 µl XL1 Blue overnight culture + 3.5 ml LB + 0.8% Top Agar. The mixture was poured over LB plates and incubated at
15 37°C overnight. Plaques were picked into 100 µl of 1X TE.

Overnight cultures were started before PCR screening with 70 µl of resuspended phage from plaques and 200 µl XL1 Blue ON in 5 ml LB. These cultures were
20 shaken at 37°C overnight. Each plaque was screened by PCR. 2 µl of the resuspended plaque in a 20 µl PCR reaction was used. Oligonucleotides 305-3 and 305-14 (internal for T7 gene 1) (See Table 1) were used for this screening. Positive clones were identified by
25 running reactions out on a 1.0% agarose gel. A 1 ml aliquot of each overnight culture was spun down and 800 µl of supernatant with phage saved in an Eppendorf tube. A 200 µl aliquot of each supernatant was then incubated at 70°C for 20 min. 100 µl of the heat
30 treated phage is then added to 500 µl of an autotrophic K strain of *E. coli* with a genotype of lac i^q (named F'tet/GM120 cells) from an overnight culture. (GM120 has ATCC Accession No. 55764). These samples were incubated at 37°C for about 1 hour. 25 µl of control
35 F'tet/GM120, 25 µl of heat treated phage alone, and 25µl of 1:10 dilution of each cross were then plated on

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LB+Kn⁴⁰ plates. The plates were then incubated at 37°C overnight. Purified colonies that resulted from the cross (or lysogenization) were streaked two times on LB+Kn⁴⁰ plates and incubated at 37°C overnight. The colonies were then subcultured two times into 0.3% ox gall bile and LB, and then shaken at 37°C overnight. Cells were then streaked on LB plates, along with a replica plating from LB to LB+Kn to identify the kanamycin sensitive colonies (the phage should no longer be present in the colonies that are kanamycin sensitive).

PCR screening was then performed to check for insertion into the chromosome as follows: a colony was picked from a plate and used to inoculate 20 µl of PCR mix (5 ml LB also inoculated, using the same tip, to be used for an overnight culture if a positive were identified). 15 µl of each PCR sample was run on a 1.0% agarose gel to check for positives. When positives were identified by size on the gel, the corresponding overnight cultures were started shaking at 37°C. These were then plated onto LB plates and incubated at 37°C overnight.

To cure the cells of the F' factor, cultures from single colonies from the plate in 5 ml LB were started shaking at 37°C for 4 hours. A published protocol for curing using acridine orange was then followed; Miller, *Experiments in molecular genetics*, Cold Spring Harbor Laboratory Press, pgs. 104-106 (1972). Basically, you plate cells to LB and replica plate to LB+tetracycline. The tetracycline sensitive cells will be isolated as F' minus. Overnight cultures of the colonies from these plates are started and then reinfected with M13 mp18 to ensure that the F' factor is no longer present in the cells. 300 µl of overnight cultures is then mixed with top agar and spotted with

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2 µl of M13 mp18 phage stock. There should be no plaques present. Two strains constructed using this protocol were named EE11-11M (PS4 promoter) and EE11-20 (UV5 lac promoter).

5 The leakage and expression characteristics of EE11-11M and EE11-20 were compared to the commercially available BL21(DE3) strain (described previously), using expression of product gene NT-3 or product gene BDNF as a marker. NT-3 (or BDNF) is present in the
10 commercially available pET22b vector (Novagen, Madison, WI) which also has a lac i site between the T7 promoter and the gene of interest, and carries a lac i^o gene to reduce leakage. Also compared were BL21(DE3) containing pLysS as a secondary vector vs. EE11-11M
15 containing pLysS as a secondary vector vs. EE11-20 containing pLysS as a secondary vector (as stated previously, pLysS carries the T7 lysozyme gene which inhibits T7 RNA polymerase and is a recommended way to reduce leakage). Finally, a pAMG25 plasmid which
20 contained the BDNF gene was also used to compare BL21(DE3) vs. EE11-20.

Specifically, overnight cultures (5 ml) of LB + antibiotic (Kn⁴⁰ or Cm³⁰) in 50 ml Falcon tubes were started and these cultures were shaken at 28°C. Fresh
25 tubes of 5 ml LB + antibiotic in 14 ml glass tubes were inoculated with 1:100 dilution of the overnight culture. Tubes were shaken at 28°C until they reached an OD₆₀₀ = ~0.8. Overnight cultures continued to shake at 28°C until the conclusion of the experiment.
30 Aliquots of each sample were taken prior to induction. Cultures were induced by the addition of 20 µl 100mM IPTG (which gave 0.4mM final concentration for IPTG). Induced cultures were incubated at 28°C with shaking for 4 hours. A 1 ml sample of the culture was
35 withdrawn and spun down in a 1.5 ml Eppendorf tube at

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15,000 rpm (at 4°C) (Tomy MTX-160) for 5 minutes. The supernatant was decanted and the pellet retained. Pellets were then resuspended in cracking buffer at 0.01 OD unit/ μ l. Samples were then heated to 100°C in
5 heat block for 5 minutes, then cooled for 2-3 minutes and then 6 μ l of each sample loaded on a 4-20% Tris-Glycine SDS polyacrylamide gel in 1X Tris-Glycine running buffer with 2% SDS added. The gel was run at 150V for 1.3 hours. The gel was stained with coomassie
10 blue to visualize the protein.

As depicted in Figure 8, which uses NT-3 as the target gene, the EE11-20 strain has no detectable leakage in either the overnight culture (ON) or prior to induction (preI), while BL21(DE3) clearly does.
15 Induction levels for NT-3 are comparable between strains. Looking at Figure 9, which uses BDNF as a target gene, EE11-20 again displays no product leakage prior to induction, although BL21(DE3) clearly does. EE11-20 does have reduced levels of BDNF in pET22b than
20 does BL21(DE3). Looking at Figure 10, levels of BDNF expressed using the pAMG25 vector were similar for EE11-20 and BL21(DE3). For each of the experiments depicted in Figures 8-10, the presence of pLyss reduced leakage, but also inhibited product expression (as had
25 been previously reported in the literature). Finally, looking at Figures 11 and 12, it is shown that EE11-11M does not display overnight or preinduction leakage but does produce comparable levels of protein as compared to BL21(DE3). Moreover, the EE11-11M strain is
30 superior to the EE11-20 strain in that the presence of lac i on the vector has no effect on protein accumulation, and in fact, may yield higher levels of some products (e.g. compare Figures 8 and 12).

It's clear from these results, that
35 additional elements which have been introduced to control leakage in the commercially available strains

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are not necessary in the strains developed in the present invention, and the strain of the present invention display both greater control of leakage and comparable levels of product expression upon induction.

5

Example 6

To determine the impact that the presence of the MS2 coat protein may have on expression of a heterologous protein in high density fermentation several products were tested. Initially, the conditions reflected the conditions that were used for small scale shake flask, a low optical density induction. An exponential culture (optical density = 1.4) of EE11-11M containing GCSF in pAMG25 was used to inoculate a 10 liter fermentor. This was grown at 28°C to an optical density 0.8 and induced with the addition of IPTG. The culture was allowed to grow an additional 10 hours after induction reaching a final optical density of 12 and samples were taken every hour. As depicted in Figure 13, there is no detectable preinduction leakage of the GCSF (lane 1) and the protein continues to be produced throughout the induction.

A second fermentation was done (using leptin in pAMG25) to test the EE11-11M strain performance at high density. An exponential inoculum (optical density = 1.32) was used to start a 10 liter fermentation. This was grown to an optical density of 10 at 28°C. The culture was then induced by the addition of IPTG. Growth was continued for 6 hours and the culture reached a final optical density of 41. As depicted in Figure 14, there is no apparent leakage prior to induction and leptin is produced well throughout the time of induction.

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These experiments show that the presence of the MS2 coat protein has no negative impact on large scale or high density fermentation.

5

Example 7

This example describes the use of the MS2 system to clone various T7 early genes. The T7 genes are cloned alone and as an operon.

10

The 0.4 and 0.6 early genes of bacteriophage T7 were PCR amplified using T7 356-DNA; Studier et al., *J. Mol. Biol.*, 135:917-937 (1979); Dunn & Studier, *J. Mol. Biol.*, 166:477-535 (1983) as a template. Each gene was PCR constructed to have an EcoRI site adjacent to the first codon of the gene (oligonucleotides 1049-5 and 1049-7) (See Table 1), and were cloned into pAMG13 which had been modified to contain an MS2 coat protein recognition site and a polyhistidine tag in frame with the multiple cloning region (oligonucleotides 1035-30 and 1035-31) (See Table 1). Oligonucleotides 1482-18 and 1266-69 (See Table 1) were used for the 0.4 gene and oligonucleotides 1266-71 and 1443-41 (See Table 1) for the 0.6 gene.

15

20

The MS2 coat protein was provided in trans from pRIN10. Electrocompetent cells containing pRIN10 were transformed by the early gene ligations with pAMG13. Positive clones were identified by PCR screening transformant colonies. Positive cultures were grown overnight as starters for expression experiments. Fresh tubes of LB Kan/Cam were inoculated at 1:100 dilution (50 μ l to 5 ml) and grown at 28°C with shaking to an O.D. of approximately 0.7. These were induced by shifting to a 42°C shaker and incubation was continued for 4 hours. Aliquots of 1 ml were removed and the cells were pelleted. Pellets were

30

35

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resuspended in cracking buffer at 0.01 OD unit/ μ l and boiled for 5 minutes. These were cooled on ice and a 6 μ l aliquot of each was run on a 10-27% SDS polyacrylamide gel.

5 Protein was then electrophoretically transferred to nitrocellulose. The blots were blocked overnight in blotto-tween with 2% non-fat dry milk. The blots were probed for 1 hour with a rabbit derived polyclonal antibody to synthetic peptide based on
10 expected protein sequence. This sera was diluted 1 to 2000. After washing the blots were probed with donkey anti-rabbit horse radish peroxidase conjugated antibody (Amersham) for 1 hour. This was washed and treated with ECL reagents (Amersham) and exposed to X-ray film.
15 The exposure was for 4 minutes. The film was developed using a Kodak film processor. As depicted in Figure 15, expression of the 0.4 gene was obtained using the MS2 controlled system. Likewise, the expression of the 0.6 gene was obtained (Figure 16).

20 Two versions of the 0.7 gene were constructed: 1) oligonucleotides 1053-66 and 1266-73 (See Table 1) were used to construct the full-length version of the gene; and 2) oligonucleotides 1053-66 and 1266-72 (See Table 1) were used to construct a
25 truncated version of the gene. The truncation was based on a mutant version that had been isolated while trying to clone the full-length version without an MS2 site in a single copy vector, and has an ochre mutation at codon 242. This early stop is similar to a mutation
30 isolated from the phage in codon 243; Studier, F.W., *J. Mol. Biol.*, 79:227-236 (1973), and that mutant was shown to have lost host shut-off activity but retained kinase activity; Michalewicz and Nicholson, *Virology*, 186:452-462 (1992).

35 An operon of the early genes was also constructed by sequential PCR. Oligonucleotides

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1511-32, 1539-60, 1803-86, 1319-59, 1577-83, 1577-84,
1539-65, 1066-72 and 1435-93 (See Table 1) were
designed to have sequence overlapping the adjacent
genes to each individual early gene and also to
5 introduce an MS2 site adjacent to the start site of
each coding region. Each gene was PCR amplified
individually using these oligonucleotides. The early
genes were then added together sequentially. The 0.4
and 0.5 genes were first linked by using both as
10 template and only using the outside primers. This
yielded a 0.4-0.5 fragment which was then used as a
half template with the 0.3 fragment and so on until a
complete 0.3 to 0.7 construct, named 3-7t operon, was
generated (SEQ ID NO:2) (Figure 17). To further reduce
15 the leakage of the early genes in the operon the
"downstream box" sequences were mutated in the 0.3, 0.6
and 0.7 genes. Most of the base changes made to reduce
"downstream box" homology were silent though one
conservative amino acid substitution did occur in each
20 of the genes.

Example 8

This example describes the results of
25 experiments wherein the 3-7t operon constructed and
described in Example 7 was used to enhance the
expression of heterologous proteins in *E. coli*. The
expression characteristics of the following systems
were compared: 1) NDF alpha/beta cloned in pAMG33, and
30 expressed in *E. coli* GM221, or with 3-7t operon in
pRIN10 expressed in *E. coli* GM221; 2) 301-941 TP2
cloned in pAMG22 and expressed in *E. coli* GM221 or with
3-7t operon in pRIN10 and expressed in *E. coli* GM221.

For each experiment, single colonies were
35 picked from plates and grown up in two 5 ml portions of
LB with Kanamycin or LB with Kanamycin and

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Chloramphenicol. The tubes shook overnight at 28°C. Four liter flasks containing 1 L of 2XYT with Kanamycin or 2XYT with Kanamycin and Chloramphenicol were set up. These were inoculated with the 10 mls of starter
5 culture. These were grown with shaking at 28°C to an O.D. of 0.8. The cultures were then shifted to 37°C with shaking for 1 hour. They were then shifted back to 28°C and taken to 0.4mM with IPTG. These were grown for an additional 3 hours with samples removed each
10 hour. The 1 ml samples were centrifuged for 5 minutes at 15K and 4°C. The supernatant was decanted and the pellet was frozen. 500 µl of each culture was diluted into 500 µl of 2XYT and the optical density was taken. Pellets were then thawed and resuspended in 0.01 OD
15 unit/µl cracking buffer. 6 µl of these cracked pellets were then loaded onto an SDS polyacrylamide gel (4-20%). After running at 150V for 1.3 hours, the gels were stained with coomassie blue to visualize the proteins.

20 As shown in Figure 18 the presence of the T7 early proteins protects NDF alpha/beta from proteolysis. When there are no T7 early proteins present, NDF alpha/beta is produced by 1 hour of induction (lane 2) but is no longer detectable by 2
25 hours of induction (lane 3). When the T7 early proteins are present, there is more NDF alpha/beta detectable and it continues to accumulate throughout the 3 hours of the induction (lanes 7-9).

30 As shown in Figure 19 the host cell does not produce 301-941 TP2 after induction in the absence of the T7 early proteins (lane 5). When the T7 early proteins are present production of the protein after induction increases dramatically (lanes 2 and 3).

35

Example 9

This example describes the construction and testing of a series of prokaryotic host strains that have been engineered to produce different concentrations of MS2CP. The host strains have the MS2CP linked to a modified TET promoter inserted into their chromosome.

10

Construction of strains A cassette of the MS2CP-14 variant linked to the TET promoter was constructed using oligonucleotides 1674-96 and 1674-97 (See Table 1). This cassette was cloned into the NotI and BamHI sites of MMeBg to generate MMeBg-MS2CP-14. The TET promoter was then optimized in stages: 1) the -10 region was taken to consensus by overlapping PCR. The mutant halves were constructed using oligonucleotides 1011-96 with 1784-89 and 1758-66 with 1674-97. The halves were then PCRed together using oligonucleotides 1674-96 and 1674-97. This was then recloned into MMeBg from NotI to BamHI to yield MMeBg-MS2CP14 (-10); 2) the -35 region was brought to consensus to produce a fully optimized TET promoter. This was again done using half reaction PCR where MMeBg-MS2CP14 (-10) served as template. Mutant halves were constructed using oligonucleotide pairs 1011-96 with 1784-88 and 1803-15 with 1674-97 (See Table 1). The two halves were then PCRed together using oligonucleotides 1674-96 and 1674-97. This was recloned into MMeBg from NotI to BamHI to yield MMeBg-MS2CP14 (fully optimized). MMeBg-MS2CP14 (-10) and MMeBg-MS2CP14 (fully optimized) both displayed increased production of MS2 coat protein over the wild type promoter construct (small increase for the (-10) and a very large increase for the fully optimized).

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To construct mutant promoter versions that would deliver levels of MS2 coat protein intermediate to the previously described mutants a strategy for randomizing the sequence of the ribosome binding site (RBS) was employed. The sequence of the promoter region containing the -10 consensus change and MS2 coat protein gene up to the KpnI site were used to design oligonucleotides 1822-01, 1822-02 and 1863-81. These oligonucleotides were phosphorylated and annealed with oligonucleotides 1821-99, 1822-03, 1822-04 and 1822-05. The product of ligation then served as a PCR template using oligonucleotides 1822-06 and 1822-07. This fragment which is now randomized in the ribosome binding sequence was able be ligated from NotI to BamHI.

To determine the effect of the ribosome binding site changes on protein production, a beta galactosidase assay was employed. Specifically, a MS2CP-14-LacZ fusion was constructed by producing a LacZ fragment with oligonucleotides 1803-52 and 1803-53 and ligating this into MMeBg-MS2CP-14 from KpnI to BamHI. This construct contains the wild type TET promoter linked to the beginning of the MS2 coat protein gene which is fused in frame with the beta galactosidase gene LacZ. The randomized RBS fragments described in the previous paragraph were then ligated into this construct from NotI to KpnI. The initial fusion and the randomized fusion ligations were integrated into the chromosome following the protocol described in Example 5. The host strain used was F'tet/393ΔlacZ145N which is deficient in beta galactosidase activity. Resolved lysogens were assayed for beta galactosidase activity as described; Miller, *Experiments in molecular genetics*, Cold Spring Harbor Laboratory Press, pgs.352-355 (1972). A series of mutants with varying levels of activity were

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identified. Three of these mutants, numbers 1, 3 and 15 were selected for the production of strains. The MMeBg-MS2CP-14-LacZ that had given rise to these particular strains were digested KpnI to BamHI to
5 remove the LacZ fusion. The MS2CP-14 gene was then regenerated by ligation of the KpnI to BamHI fragment into these vectors. Strains were constructed from these three mutants and the MMeBg-MS2CP-14 (fully optimized) by integration into host strain 393. The
10 resultant strains were named GM315 (mutant 1), GM320 (mutant 3), GM340 (mutant 15) and GM350 (fully optimized).

Testing of strains to produce MS2CP The ability of
15 these strains to produce MS2 coat protein was determined by western analysis of exponential cultures. Colonies of each strain were picked from plates and used to inoculate 5 mls of LB. These were grown with shaking at 30°C to an optical density of 0.7. One ml
20 samples were taken. All samples were pelleted by centrifugation and the pellets were resuspended in cracking buffer. After boiling for 5 minutes, a 6 µl aliquot of each was run on a 4-20% SDS polyacrylamide gel (Novex). Protein was then electrophoretically
25 transferred to nitrocellulose. The blots were blocked overnight in blotto-tween with 2% non-fat dry milk; Harlow & Lane, *Immunoblotting in Antibodies*, A Laboratory Manual, Chapter 12, Cold Spring Harbor Laboratory Press, (1988). The blots were probed for 1
30 hour with a rabbit derived polyclonal antibody to MS2 coat protein. After washing the blots were probed with donkey anti-rabbit horse radish peroxidase conjugated antibody (Amersham) for 1 hour. This was washed and treated with ECL reagents (Amersham) and exposed to X-
35 ray film. The film was developed using a Kodak film processor. As shown in Figure 20, the level of MS2

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coat protein passively expressed during log phase growth is detectable over background at low levels in GM315 and GM320 and increases considerably in GM340 and GM350.

5

Cloning heterologous genes using the strains Using conventional techniques, N-terminal his tag fusions of the ns5b gene of hepatitis C (the Hep C polymerase) were found to be very difficult to clone. When full-length versions of the gene were isolated they contained mutations that led to early stops of translation or that were in the ATG and prevented translational initiation altogether. To facilitate the cloning of this gene, an MS2 recognition sequence was linked to it, and the ligations used to first transform strain GM350. Full-length inserts were detected, sequenced, and determined to be correct.

The recombinant his-tagged ns5b gene obtained from GM350 was then placed in pAMG21 and used to transform GM221, GM315 and GM320 (GM221 does not contain MS2 coat protein while GM315 and GM320 produce lower levels than GM350). The gene was found to be stable in all three cell lines.

The ability of the various strains to produce the his-tagged hepC polymerase was then determined. Overnight cultures were used to inoculate 50 ml of 2XYT in 250 ml erlenmeyer flasks at a 1 to 100 dilution. These were grown with shaking at 30°C to an optical density of 0.6. The pAMG21 vector contains a lux promoter and so the production of the hepC polymerase is accomplished by the addition of autoinducer at a final concentration of 30 ng/ml. Incubation is continued for 4 hours and samples are taken. Cells are pelleted by centrifugation. The pellets were resuspended in 10 ml PBS and this was microfluidized. The samples were centrifuged to separate the soluble

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and insoluble fractions. These were mixed with cracking buffer and samples were run on 4-20% SDS gels. After running at 150V for 1.3 hours the gels were stained with coomassie blue to visualize the proteins.

5 As depicted in Figure 21, the hepC polymerase is produced in all three strains. The majority of the protein produced is insoluble. There may be somewhat higher expression in the MS2 coat protein containing strains. This example thus demonstrates a way in which
10 these strains may be employed: the highest producer, GM350, is used to initially clone the unstable gene; and, once a stable clone is obtained and confirmed as correct, it may be transformed into the remaining strains and the ability to produce the protein product
15 as well as the sustainable stability of the gene may be determined.

Example 10

20 This example describes the construction of the pAMGuvxs plasmid vector, the pAMGX plasmid vector, and the T4 operon pRIN plasmid vectors used to develop the T4 middle promoter based system.

Bacteriophage T4 middle promoters were
25 constructed synthetically using the published sequences of PuvS_X and P_X; Hinton, D.M., *J. Biol. Chem.*, 266(27):18034-18044 (1991) (uvS_X: oligonucleotides 1084-66 and 1084-67 (See Table 1), X: oligonucleotides 1084-68 and 1084-69) (See Table 1). The PuvS_X promoter
30 was reconstructed to remove the NdeI site it contains (oligonucleotides 1202-11 and 1550-85) (See Table 1). Each construct was designed to have AatII and ClaI restriction sites. The complete base sequence of the PuvS_X promoter construct is depicted in Figure 22, and
35 the complete gene sequence of the P_X promoter construct is depicted in Figure 23. The plasmid pAMG13 was

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digested with AatII and ClaI to remove the synthetic lambda promoter and the vector was gel purified. The T4 middle promoters were then each ligated with this plasmid to create plasmid vectors pAMGuvsX and pAMGX.

5 The motA/asiA operon was constructed such that each gene was preceded by an MS2 coat protein recognition sequence. The published sequence of motA; Uzan et al., *Mol. Microbiol.*, 4(9):1487-1496 (1990), and asiA; Orsini et al., *Jour. Bacteriology*, 175(1):85-10 93 (1993) were used for the construction. At the beginning of the fragment was an XbaI site and at the end was a XhoI site (oligonucleotides 1084-63, 1528-19, 1528-20, and 1703-53) (See Table 1). This fragment was digested with XbaI and XhoI and then ligated with 15 several pRIN plasmid vectors to provide, for example, T4 operon pRIN10 plasmid vector, T4 operon pRIN11 plasmid vector, etc.

Example 11

20

This example describes the testing of the pAMGuvxs, pAMGX and T4 operon pRIN plasmid vectors prepared and described in Example 10. Specifically, expression experiments were carried out to test the 25 ability of the systems to prevent leakage and allow for expression of product gene. The expression and leakage characteristics of the following systems were compared: 1) T7 gene 1 cloned and expressed in *E. coli* host GM221 (ATCC Accession No. 202077) containing the pAMG13 30 vector (i.e., T7 gene 1 under the control of the lambda promoter); 2) T7 gene 1 cloned and coexpressed with T4 operon pRIN10 in *E. coli* host GM221 containing pAMG13; 3) T7 gene 1 cloned and coexpressed with T4 operon pRIN10 in *E. coli* host GM221 containing pAMGuvsX (i.e., 35 T7 gene 1 under control of uvsX T4 middle promoter; 4) T7 gene 1 cloned and coexpressed with T4 operon pRIN11

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in *E. coli* host GM221 containing pAMGuvsX; 5) NT-3 cloned and coexpressed with T4 operon pRIN10 in *E. coli* host GM225 containing pAMGuvsX; and 6) BDNF cloned and coexpressed with T4 operon pRIN10 in *E. coli* host GM225 containing pAMGuvsX.

For each experiment, single colonies were picked from plates and grown up in 5 ml 2XYT with Chloramphenicol and Kanamycin. The tubes shook overnight at 28°C. 50 ml tubes were set up with 5 ml 2XYT with Chloramphenicol and Kanamycin. The fresh tubes were inoculated with 50 µl of the starter cultures. These tubes were grown with shaking at 28°C to an O.D. of 0.6-1.2. The PS4 promoter containing cultures (pRIN11) were induced with 20 µl IPTG, while the lambda promoter containing cultures (pAMG) were induced by shifting to either 37°C or 42°C. Induction time for all of these expression experiments was 4.0 hours. 1 ml of each culture was centrifuged for 10 minutes. The supernatant was decanted and the pellet was frozen. 500 µl of each culture was diluted into 500 µl of 2XYT and the optical density was taken. Pellets were then thawed and resuspended in 0.01 OD unit/µl cracking buffer. 6 µl of these cracked pellets were then loaded onto an SDS polyacrylamide gel (4-20% or 16%). After running at 150V for 1.3 hours the gels were stained with coomassie blue to visualize the proteins.

The data from Figures 24-29 can be summarized as follows: 1) the pAMG13 vector is capable, upon induction, to produce abundant levels of T7 RNA polymerase when the T7 gene 1 is under the control of the lambda promoter (see lanes 3 and 4, Figure 24); 2) T4 operon protein products sufficiently abolish the recognition of the lambda promoter by the *E. coli* RNA polymerase (compare lanes 2 and 3 of Figure 25 with

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lanes 3 and 4 of Figure 24); 3) abundant levels of T7 RNA polymerase can be obtained in pAMGuvsX wherein T7 gene 1 is cloned and coexpressed with T4 operon pRIN10 (compare lanes 3 and 4 of Figure 24 with lanes 2 and 3 of Figure 26); 4) coexpression with T4 operon pRIN11 is as effective in producing T7 gene 1 as is T4 operon pRIN10 (compare lanes 3 and 4 of Figure 27 with lanes 2 and 3 of Figure 26); and 5) abundant levels of NT-3 and BDNF can also be obtained from pAMGuvsX wherein the NT-3/BDNF is cloned and coexpressed with T4 operon pRIN10 (compare Figures 28 and 29 with Figure 26).

Example 12

This example describes the cloning of the motA/asiA operon into single copy plasmids containing the MS2 system.

Single copy vectors were derived from pSC101; Bernardi and Bernardi, *Nuc. Acids Res.*, 12:9415-9426. This vector was digested with NdeI and then recircularized to yield plasmid pSC101dNde. A DNA linker containing BglII and NsiI sites was introduced into the EcoRI site of this plasmid. A fragment of pAMG22 from NsiI to BglII which contains the T1T2, PS4 promoter and the multiple cloning site was then cloned in to create plasmid pTS2. pTS2 was then cut with MluI and XmnI, the ends were blunted using Klenow fragment; Sambrook et al., *Molecular cloning, a laboratory manual*, Second edition, Cold Spring Harbor Laboratory Press, pgs. 5.40-5.41 (1989), and the plasmid was recircularized to yield pTS2d. Fragments of the pRIN plasmid vectors containing the target promoter, MS2 recognition site, MS2CP gene and TET promoter were generated by PCR using oligonucleotides 828-31 and 1553-72 (See Table 1). These fragments were digested with AatII and BglII and then ligated into pTS2d to

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create pCB plasmid vectors (see Figure 30). The motA/asiA operon described in Example 10 was then cloned into these pCB plasmid vectors from XbaI to XhoI to create pAW plasmid vectors (see Figure 31).

5 Another single pCB plasmid was constructed using the mutated TET promoter for the control of the MS2 coat protein. A cassette of the MS2 coat protein gene linked to the TET promoter was PCR constructed using oligonucleotides 1870-97 and 1906-27 (See Table
10 1). This fragment was digested XhoI to BglII and ligated into pTS2d to create pCB11. The motA/asiA operon described in Example 10 was then cloned into this vector from XbaI to XhoI to create pAW11 (Ps4 promoter).

15

Example 13

This example describes the testing of the pAW plasmid vectors prepared and described in Example 12.
20 Expression experiments were carried out in which product genes were cloned under either the T4 uvsX or X promoters. The expression and leakage characteristics of the following systems were compared: 1) T7 gene 1 cloned and coexpressed with pAW20 in *E. coli* GM221
25 containing pAMGX (i.e., T7 gene 1 under control of T4 X promoter; 2) SPI cloned and coexpressed with pAW20 in *E. coli* GM225 containing pAMGX (i.e., SPI under control of T4 X promoter; 3) OPG cloned and coexpressed with pAW20 in *E. coli* GM225 containing pAMGuvsX (i.e., OPG
30 under control of T4 uvsX promoter); 4) BDNF cloned and coexpressed with pAW11 in *E. coli* GM225 containing pAMGuvsX (i.e., BDNF under control of T4 uvsX promoter; 5) OPG cloned and coexpressed with pAW11 in *E. coli* GM225 containing pAMGuvsX (i.e., OPG under control of
35 T4 X promoter; 6) NT3 cloned and coexpressed with pAW11 in *E. coli* GM225 containing pAMGuvsX (i.e., NT3 under

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control of T4 uvsX promoter; and 7) 3MNDF cloned and coexpressed with pAW11 in *E. coli* GM225 containing pAMGX (i.e., 3MNDF under control of T4 X promoter.

For each experiment, single colonies were
5 picked from plates and grown up in 5 ml 2XYT with Tetracycline and Kanamycin. The tubes shook overnight at 28°C. 50 ml tubes were set up with 5 ml 2XYT with Tet and Kan. The fresh tubes were inoculated with 50 µl of the starter cultures. These tubes were grown
10 with shaking at 28°C to an O.D. of 0.6-1.2. The PS4 promoter containing cultures and UV5 lac promoter containing cultures were induced with 20 µl IPTG, while the lambda promoter containing cultures were induced by shifting to either 37°C or 42°C. Induction time for
15 all of these expression experiments was 4.0 hours. 1 ml of each culture was centrifuged for 10 minutes. The supernatant was decanted and the pellet was frozen. 500 µl of each culture was diluted into 500 µl of LB and the optical density was taken. Pellets were then
20 thawed and resuspended in 0.01 OD unit/µl cracking buffer. 6 µl of these cracked pellets were then loaded onto an SDS polyacrylamide gel (4-20% or 16%). After running at 150V for 1.3 hours the gels were stained with coomassie blue to visualize the proteins.

25 The data from Figures 32-34 can be summarized as follows: 1) abundant levels of T7 gene 1 can be obtained in pAMGX wherein T7 gene 1 is cloned and coexpressed with pAW20 (Figure 32); 2) abundant levels of SPI can be obtained in pAMGX wherein SPI is cloned
30 and coexpressed with pAW20 (Figure 33); and 3) abundant levels of OPG can be obtained in pAMGuvsX wherein OPG is cloned and coexpressed with pAW20 (Figure 34).

The data from figures 35-38 can be summarized as follows: 1) abundant levels of BDNF can be obtained
35 in pAMGuvsX wherein BDNF is cloned and coexpressed with

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pAW11 (Figure 35); 2) abundant levels of OPG can be obtained in pAMGuvsX wherein OPG is cloned and coexpressed with pAW11 (Figure 36); 3) abundant levels of NT3 can be obtained in pAMGuvsX wherein NT3 is
5 cloned and coexpressed with pAW11 (Figure 37); 4) abundant levels of 3MNDF can be obtained in pAMGX wherein 3MNDF is cloned and coexpressed with pAW11 (Figure 38).

Because testing with the single copy pAW
10 plasmids provides a system similar to that which would occur if the MS2-based T4 cassette were placed on the chromosome, it is contemplated by the present invention that each of the required MS2-T4 middle promoter elements could be placed on the chromosome of the host
15 cell to provide an effective, tightly controlled system.

Example 14

20 This example describes the use of the MS2-based T4 system to effectively express an accessory protein and thereby enhance expression of a target protein.

A T4 operon containing *motA* and *asiA* was PCR
25 constructed to have a *XhoI* site at the start, followed by an MS2 recognition site, and a *BamHI* site at the end of the *asiA* gene which is also preceded by an MS2 recognition site (oligonucleotides 1351-01 and 1260-86) (See Table 1) This fragment was then cloned into
30 the corresponding sites of pRIN10 (giving T4 operon pRIN10).

The 0.6 gene of T7 was constructed to have an *XbaI* site followed by an MS2 recognition site and ending with a *XhoI* site (oligonucleotides 1443-41 and
35 1465-31) (See Table 1). This 0.6 fragment was then put into the T4 operon pRIN10 using the corresponding

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sites. This yields a plasmid (0.6 T4 operon pRIN10) that can express both the 0.6 gene and the T4 transcription factors. Expression experiments were then carried out (following the same experimental protocol as described in Example 11) using a system wherein BDNF was cloned and coexpressed with 0.6 T4 operon pRIN10 in *E. coli* host GM225 containing pAMGuvsX (i.e., BDNF under the control of the T4 uvsX middle promoter).

As depicted in Figure 39, abundant levels of BDNF could be obtained using this system, and the levels obtained were superior to those obtained using a T4 operon pRIN10 system lacking the 0.6 gene (compare lanes 4 and 5; Figure 29 to lanes 4 and 5, figure 39). Therefore, the accessory protein (0.6) enhanced expression of target protein in a staged promoter expression system.

Provided in Table 1 below are the oligonucleotides utilized in the examples described herein.

Table 1

909-34	(SEQ ID NO:5)	TATGGCTTCTAACTTCACTCAGTTCGTA
909-35	(SEQ ID NO:6)	GCCTTGTCACCAGTACGAACTGAGTGAAGTTAGAAGCCA
909-36	(SEQ ID NO:7)	AACGGCGGTACCGCGGATGTA
		TC
909-37	(SEQ ID NO:8)	ATTTGCGAAGTTGGACGGTGCAACAGTTACATCGCCGGTACC
909-38	(SEQ ID NO:9)	GCAAATGGCGTTGCTGAATGGATTTCTTCCA
909-39	(SEQ ID NO:10)	GCTGCGAGAGTTGGAAGAAATCCATTCAGCAACGCC
909-40	(SEQ ID NO:11)	CGCAGCCAGGCTTACAAAGTA
		CC

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909-41	(SEQ ID NO:12) TGCAGAGGACTGGCGAACGCTGCAAGTTACTTTGTAAGCC TG
909-42	(SEQ ID NO:13) TCTGCACAAAACCGAAAATACACCATCAAGGTAGAA
909-43	(SEQ ID NO:14) CGGGACTTCTACCTTGATGGTGTATTTTCGGTTTTG
909-44	(SEQ ID NO:15) GTCCCGAAAGTTGCGACCCAGACTGTAGGCGGTGTGCAAC TG
909-45	(SEQ ID NO:16) AACCGGCAGTTCGACACCGCCTACCGTCTGGGTCGCAACT TT
909-46	(SEQ ID NO:17) CCGGTTGCTGCATGGCGCAGCTACCTGAACATGGAA
909-47	(SEQ ID NO:18) CGTCAGTTCATGTTTCAGGTAGCTGCGCCATGCAGC
909-48	(SEQ ID NO:19) CTGACTATCCCGATTTTCGCAACCAACTCTGACTGTGAAC TG
909-49	(SEQ ID NO:20) TACGATCAGTTCACAGTCAGAGTTGGTTGCGAAAATCGGG AT
909-50	(SEQ ID NO:21) ATCGTAAAAGCTATGCAGGGTCTGCTAAAAGAT
909-51	(SEQ ID NO:22) ATTGCCATCTTTTAGCAGACCCGTCATAGCTTT
909-52	(SEQ ID NO:23) GGCAATCCAATTCGTCGCAATCGCTGCAAACCTCTGGTA TCTACTAATAG
909-53	(SEQ ID NO:24) GATCCTATTAGTAGATACCAGAGTTTGCAGCGATTGCGGA CGGAATTGG
1456-55	(SEQ ID NO:25) CGCAAATGGCATTGCTGAATGG
1456-56	(SEQ ID NO:26) CCATTCAGCAATGCCATTTGCG
1456-61	(SEQ ID NO:27) CCAACTCTGACCGTGAACGATCG
1456-62	(SEQ ID NO:28) CGATCAGTTCACGGTCAGAGTTGG
940-29	(SEQ ID NO:29) AGCTGGTGAGCTCGATCATTGGGCATACGCATGCTGCAGC GC
940-30	(SEQ ID NO:30) TCTAGGCGCTGCAGCATGCGTATGCCCAATGATCGAGCTC ACC
941-43	(SEQ ID NO:31) GGCCAATCGCGAATTGACGTCACGTTGAGAATT
941-44	(SEQ ID NO:32) GGCCAATTCTGAACGTGACGTCAATTCGCGATT
1036-99	(SEQ ID NO:33) ATGCATCGAGCTCGATTAGGACATGGGGCCTCGCT
1016-20	(SEQ ID NO:34) GCCGCGCGAGCTCGTTGTAATTCTCATGTTTGACAGCTT ATCATCGATAAGCTTTAATGCGGTAGTTT
1016-21	(SEQ ID NO:35) GGGAATTCATATGCGGTGCCTGACTGCGTTAGCAATTTA ACTGTGATAAACTACCGCATTAAGC
1036-6	(SEQ ID NO:36) GATTCCCCGGGCAAATAAAACGAAAGGCTCAGTCGAAAG AC

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1053-71	(SEQ ID NO:37) CTGATCGCGACGTCTTG TAGAAACGCAAAAAGGCCATCCG TCAG
949-1	(SEQ ID NO:38) GCTCTAGAAACATGAGGATTACCCATGAACACGATTAACA TCGCTAAGAACGACTTCTCTGAC
949-2	(SEQ ID NO:39) CGGGATCCGTCATTACGCGAACGCGAAGTCCGACTC
1477-84	(SEQ ID NO:40) GCGCGCTCTAGAAAACATGAGGATTACCCATGAATACCAT CAATATCGCTAAGAACGACTTCTCTGACATC
1553-73	(SEQ ID NO:41) GGCCAGTGCATGCCTACGTGGGTCCTAGTCGC
1553-74	(SEQ ID NO:42) GATCGCGACTAGGACCCACGTAGGCATGCACTG
305-3	(SEQ ID NO:43) CTGAATACGCTGAGGCTA
305-14	(SEQ ID NO:44) TCAGCCAGTAGTAACCTT
1049-5	(SEQ ID NO:45) GCGCGCGAATTCTTTTCGATCTACTACCAACGTGCAATACG GTCTGACC
1049-7	(SEQ ID NO:46) GCGCGCGAATTCTTTTCGAATGAAGCACTACGTTATGCCAA TCCACACG
1035-30	(SEQ ID NO:47) CTAGAGCAAACATGAGGATTACCCATGAAACATCACCATC ACCATCACCATAACCGGTGGCG
1035-31	(SEQ ID NO:48) AATTCGCCACCGGTATGGTGATGGTGATGGTGATGTTTCA TGGGTAATCCTCATGTTTGCT
1482-18	(SEQ ID NO:49) GCGCGCTCTAGAAAACATGAGGATTACCCATGTCTACTAC CAACGTGCAATACGGTCTGACC
1266-69	(SEQ ID NO:50) GCGCGCGGATCCGAGTCTATCACTCAGCAGATTCTA
1266-71	(SEQ ID NO:51) GCGCGCGGATCCCTATTATGAGATAGCGTTCAGTGTGTTG GC
1053-66	(SEQ ID NO:52) GCGCGCCTCAGAAAACATGAGGATTACCCATGAACATTAC CGACATCATGAACGCTATCGACGCAATCA
1266-73	(SEQ ID NO:53) GCGCGCGGATCCCTATCAGCCCATTAACATTGCGTC
1266-72	(SEQ ID NO:54) GCGCGCGGATCCCTATCATGCGACTTCCTCGACTTC
1511-32	(SEQ ID NO:55) GCGCGCTCTAGAAAACATGAGGATTACCCATGGCTATGTC TAATCTCACATATAACAACGTTTTTCGAC
1539-60	(SEQ ID NO:56) CACGTTGGTAGTAGACATGGGTAATCCTCATGTTTTTACT CTTTCATCCTCCTCGTACTCC
1539-65	(SEQ ID NO:57) GTCGGTAATGTTTCATGGGTAATCCTCATGTTTTTATGAGA TAGCGTTCAGTGTGTTGG
1803-86	(SEQ ID NO:58) AGCATATACATGGGTAATCCTCATGTTTGAGTCTATCACT CAGCAGATTCTAAAGC

1319-59	(SEQ ID NO:59) CTGCTGAGTGATAGACTCAAACATGAGGATTACCCATGTATATGC
1577-83	(SEQ ID NO:60) CATAACGTAATGCCGCATGGGTAATCCTCATGTTTTTCATCATTTGCGTAGTGCCCCCTTTGATG
1577-84	(SEQ ID NO:61) CATCAAAGGGGCACTACGCAAATGATGAAAACATGAGGATTACCCATGCGGCATTACGTTATG
1066-72	(SEQ ID NO:62) GAACGCTATCTCATAACGAAACATGAGGATTACCCATGAACATTACCG
1435-93	(SEQ ID NO:63) GCGCGGATCCCTATCATGCGACTTC
1084-66	(SEQ ID NO:64) GCGCGCGACGTCGGCAAAAAGCAGTCAGAAGAACTAAAGCAGCAAAACGAAAAGAAGCTTTGCTT
1084-67	(SEQ ID NO:65) GCGCGCATCGATTGATGGTTTATTTCTATTATAACCATATGGATTATTAAGCAAAGCTTCTTT
1084-68	(SEQ ID NO:66) GCGCGCGACGTCGTAGAGTCAATGAGTTAAAACACAGTGATGTTTTGCGTAAAGAGAT
1084-69	(SEQ ID NO:67) GCGCGCATCGATGCACGGGTTTTATTTAAATATCATGTTGAATAGAAAGCATCTCTTTACGC
1202-11	(SEQ ID NO:68) GCGCGCGACGTCGGCAAAAAGCAGTCAGAAGAACTAAAGCAAACGAAAAGAAGCTTTGCTT
1550-85	(SEQ ID NO:69) GCGCGCATCGATTGATGGTTTATTTCTATTATAACGATATAGATTATTAAGCAAAGCTTCTTT
1084-63	(SEQ ID NO:70) GCGCGCTCTAGAAAACATGAGGATTACCCATGTCTAAAGTAACCTACATCATCAAAGCTTCTA
1528-19	(SEQ ID NO:71) TGTATCAATGTTTTTATTCATGGGTGATCCTC
1528-20	(SEQ ID NO:72) ATGAATAAAAACATTGATACAGTTCGTG
1703-53	(SEQ ID NO:73) GCGCGCCTCGAGCTATTATTTGTTTCGTATACATCTCCAGGTATCGATA
828-31	(SEQ ID NO:74) GGATGGCCTTTTTGCGTTTCT
1553-72	(SEQ ID NO:75) GCGCGCAGATCTGAAGATCTTATTAATCAGATAAAATATTCTAGGCG
1351-01	(SEQ ID NO:76) GCGCGCCTCGAGAAAACATGAGGATTACCCATGTCTAAAGTAACCTACATCATCAAAGCTTCTA
1260-86	(SEQ ID NO:77) GCGCGCGGATCCCTATTATTTGTTTCGTATACATCTCCAGGTATCGATA
1443-41	(SEQ ID NO:78) GCGCGCTCTAGAAAACATGAGGATTACCCATGATGAAGCACTACGTTATGCCAATCCACACGTCC
1465-31	(SEQ ID NO:79) GCGCGCCTCGAGCTATTATGAGATAGCGTTCAG

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1870-97	(SEQ ID NO:80) GCGCGCGCATGCAGATCTGTATGCCCAATGATCGAGCTGTT GTAATTCTC
1906-27	(SEQ ID NO:81) GCGCGCCTCGAGCCGCGGCTATTAGTAGATACCAGAGTT TGC
1674-96	(SEQ ID NO:82) CAACACCCAGCGGCCGCTGCGTATCAATGATCGAGCTGT
1674-97	(SEQ ID NO:83) AAGCTTACTCGAGGATCCCTATTAGTAGATACCAGAGT
1011-96	(SEQ ID NO:84) GCTGCCGCTGTTAGTCTTCGTTCC
1784-89	(SEQ ID NO:85) CTACCGCATTATAGCTTATCGATGATAAGCT
1758-66	(SEQ ID NO:86) CGATAAGCTATAATGCGGTAGTTTACAGTTAAA
1784-88	(SEQ ID NO:87) TTATTCCTCCTTGC GTTAGCAATTAACTGTGATAAACTA CCGCATTATAGCTTATCG
1803-15	(SEQ ID NO:88) CGATAAGCTATAATGCGGTAGTTTATCACAGTTAAATTGC TAACGCAAGGAATAACATATGGCTTCTAACTTCACTCAG
1803-52	(SEQ ID NO:89) CCACCACCGGGTACCGTCGTTTTACAACGTCGTGACTGG
1803-53	(SEQ ID NO:90) CCACCACACGGATCCTTATTTTTGACACCAGACCAACT
1822-01	(SEQ ID NO:91) AGTTAAATTGCTAACGCA (AG) (AG) (AG) (AG) GGCACC GCATATGCTTCTAACTTCACTCA
1822-02	(SEQ ID NO:92) GTTCGTACTGGTTGACAACGGCGGTACCCACAGTGACTATA TGGGTGGCA
1822-03	(SEQ ID NO:93) ATCGATGATAAGCTGTCAATAATGAGAATT
1822-04	(SEQ ID NO:94) GTTAGCAATTAACTGTGATAAACTACCGC
1822-05	(SEQ ID NO:95) TCAACCAGTACGAAGTGAAGTTAGAA
1863-81	(SEQ ID NO:96) CAGCTTATCATCGATAAGCTATAATGCGGTAGTTAATCAC
1822-06	(SEQ ID NO:97) TGACACACGGTCAATGGTTGG
1822-07	(SEQ ID NO:98) TGCCACCCATATAGTCACTGTGG

Deposits of DNA/Host cells

5 *E. coli* K-12/GM350 host cells were deposited with the ATCC (American Type Culture Collection, 12301 Parklawn Drive, Rockville, MD, USA) on January 20, 1999.

10 *E. coli* K-12/GM225 host cells have been deposited with the ATCC (American Type Culture Collection, 12301 Parklawn Drive, Rockville, MD, USA) on January 27, 1998, and assigned accession No. 20281.

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E. coli K-12/GM225 host cells containing plasmid vector pAMG13 have been deposited with the ATCC (American Type Culture Collection, 12301 Parklawn Drive, Rockville, MD, USA) on January 27, 1998, and
5 assigned accession No. 98641.

E. coli K-12/GM225 host cells containing plasmid vector pAMG25 have been deposited with the ATCC (American Type Culture Collection, 12301 Parklawn Drive, Rockville, MD, USA) on January 27, 1998, and
10 assigned accession No. 98642.

E. coli K-12/GM225 host cells containing plasmid vector 3002 nahG have been deposited with the ATCC (American Type Culture Collection, 12301 Parklawn Drive, Rockville, MD, USA) on January 27, 1998, and
15 assigned accession No. 98645.

E. coli K-12/GM225 host cells containing plasmid vector pRIN10(wt) have been deposited with the ATCC (American Type Culture Collection, 12301 Parklawn Drive, Rockville, MD, USA) on January 27, 1998, and
20 assigned accession No. 98639.

E. coli EE11-11M host cells have been deposited with the ATCC (American Type Culture Collection, 12301 Parklawn Drive, Rockville, MD, USA) on January 27, 1998, and assigned accession No. 202083.
25

E. coli EE11-20 host cells have been deposited with the ATCC (American Type Culture Collection, 12301 Parklawn Drive, Rockville, MD, USA) on January 27, 1998, and assigned accession No. 202082.

E. coli K-12/GM225 host cells containing plasmid vector pAMGuvsX have been deposited with the ATCC (American Type Culture Collection, 12301 Parklawn Drive, Rockville, MD, USA) on January 27, 1998, and
30 assigned accession No. 98644.

E. coli K-12/GM225 host cells containing plasmid vector pAMGX have been deposited with the ATCC (American Type Culture Collection, 12301 Parklawn
35

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Drive, Rockville, MD, USA) on January 27, 1998, and assigned accession No. 98643.

E. coli K-12/GM225 containing plasmid vector T4 operon pRIN10 have been deposited with the ATCC
5 (American Type Culture Collection, 12301 Parklawn Drive, Rockville, MD, USA) on January 27, 1998, and assigned accession No. 98640.

E. coli K-12/GM225 host cells containing plasmid vector pAW20 have been deposited with the ATCC
10 (American Type Culture Collection, 12301 Parklawn Drive, Rockville, MD, USA) on January 28, 1998, and assigned accession No. 98638.

E. coli K-12/FM-15 host cells containing plasmid vector pAMG21 were deposited with the ATCC
15 (American Type Culture Collection, 12301 Parklawn Drive, Rockville, MD, USA) and assigned accession No. 98113.

E. coli K-12/GM221 host cells containing plasmid vector pAMG33 were deposited with the ATCC
20 (American Type Culture Collection, 12301 Parklawn Drive, Rockville, MD, USA) on January 20, 1999.

Plasmid vector pAMG22 has been deposited with the ATCC (American Type Culture Collection, 12301 Parklawn Drive, Rockville, MD, USA) on January 28,
25 1998, and assigned accession No. 98646.

The present invention has been described in terms of particular embodiments found or proposed to comprise preferred modes for the practice of the
30 invention. It will be appreciated by those of ordinary skill in the art that, in light of the present disclosure, numerous modifications and changes can be made in the particular embodiments exemplified without departing from the intended scope of the invention.

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WHAT IS CLAIMED IS:

1. A translational repression system for
5 use in cloning or expressing a specific heterologous
gene, said system comprising a translational repressor
operably linked to a constitutive promoter.

2. The system of Claim 1, wherein said
10 translational repressor is bacteriophage MS2 coat
protein (MS2CP).

3. An improved process for cloning or
expressing a heterologous gene, said process
15 comprising:
culturing, under suitable conditions, host
cells transformed with a plasmid vector, said vector
comprising a DNA sequence encoding an inducible
promoter, a DNA sequence encoding said heterologous
20 gene linked to a translational repressor recognition
site, and a DNA sequence encoding a translational
repressor operably linked to a constitutive promoter;
wherein said translational repressor controls
expression of said heterologous gene.

25

4. An improved process for cloning or
expressing a heterologous gene, said process
comprising:

30 culturing, under suitable conditions, host
cells which have been co-transformed with a first
plasmid vector comprising a DNA sequence encoding an
inducible promoter and said heterologous gene linked to
a translational repressor recognition site, and a
second plasmid vector comprising a DNA sequence
35 encoding a translational repressor operably linked to a
constitutive promoter; wherein said translational

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repressor controls expression of said heterologous gene.

5 5. An improved process for cloning or
expressing a heterologous gene, said process
comprising:

 culturing, under suitable conditions, host
cells harboring a DNA sequence encoding a translational
repressor operably linked to a constitutive promoter,
10 transformed with a plasmid vector, said vector
comprising a DNA sequence encoding an inducible
promoter, and a DNA sequence encoding said heterologous
gene linked to a translational repressor recognition
site; wherein said translational repressor controls
15 expression of said heterologous gene.

 6. An improved process for cloning or
expressing a heterologous gene, said process
comprising:

20 culturing, under suitable conditions, host
cells harboring a DNA sequence encoding an inducible
promoter, a DNA sequence encoding said heterologous
gene linked to a translational repressor recognition
site, and a DNA sequence encoding a translational
25 repressor operably linked to a constitutive promoter;
wherein said translational repressor controls
expression of said heterologous gene.

 7. A process of any of Claims 3-6, wherein
30 said translational repressor is bacteriophage MS2 coat
protein.

 8. A process of any of Claims 3-5, wherein
said vector further comprises SEQ ID NO:2.

35

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9. An "MS2 controlled T7 gene 1 cassette", said cassette comprising a DNA sequence encoding an inducible promoter, the MS2 recognition site linked to T7 gene 1, and the MS2 coat protein gene under the control of a weak constitutive promoter.

10. A host cell capable of expressing a heterologous gene and harboring an "MS2 controlled T7 gene 1 cassette".

11. An improved process for expressing a heterologous gene, said process comprising:
culturing, under suitable conditions, host cells harboring an "MS2 controlled T7 gene 1 cassette" and transformed with a plasmid vector containing a DNA sequence encoding said heterologous gene under the control of a T7 promoter.

12. A process of Claim 11, wherein said heterologous gene is a T7 early gene.

13. A series of host cells capable of cloning or expressing a heterologous gene, said host cells engineered to produce different concentrations of MS2CP.

14. A staged inducible promoter system for cloning or expressing a heterologous gene, said system comprising regulated transcriptional control proteins that direct transcription from specific promoters, while inhibiting general transcription from bacterial host promoters.

15. A system of Claim 14, wherein said transcriptional control proteins are motA and asiA, and

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said proteins are regulated by a translational repressor.

16. An improved process for cloning or
5 expressing a heterologous gene, said process comprising:

culturing, under suitable conditions, host
cells which have been co-transformed with a first
plasmid vector comprising a DNA sequence encoding said
10 heterologous gene under the control of T4 middle
promoter, and a second plasmid vector comprising a DNA
sequence encoding an inducible promoter, motA and asiA
gene sequences each linked to a translational repressor
recognition site, and a translational repressor
15 operably linked to a constitutive promoter; wherein
said translational repressor controls expression of
said motA and asiA genes, and wherein said motA and
asiA genes direct transcription from the T4 middle
promoter while inhibiting transcription from said
20 inducible promoter.

17. A process of Claim 16, wherein said
second plasmid vector further comprises a DNA sequence
encoding an accessory protein.

25

18. An improved process for cloning or
expressing a heterologous gene, said process
comprising:

culturing, under suitable conditions, host
30 cells harboring a DNA sequence encoding an inducible
promoter, motA and asiA gene sequences each linked to a
translational repressor recognition site, and a
translational repressor operably linked to a
constitutive promoter, transformed with a plasmid
35 vector comprising a DNA sequence encoding said
heterologous gene linked under the control of T4 middle

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promoter; wherein said translational repressor controls expression of said motA and asiA genes, and wherein said motA and asiA genes direct transcription from the T4 middle promoter while inhibiting transcription from said inducible promoter.

19. A process of any of Claims 16-18, wherein said translational repressor is bacteriophage MS2 coat protein.

20. An "MS2-based T4 cassette", said cassette comprising a DNA sequence encoding an inducible promoter, motA and asiA gene sequences each linked to an MS2 recognition sequence, and the MS2 coat protein gene under the control of a constitutive promoter.

21. A prokaryotic host cell capable of expressing a heterologous gene and harboring an "MS2-based T4 cassette".

22. An improved process for cloning or expressing a heterologous gene, said process comprising:

25 culturing, under suitable conditions, host cells harboring an "MS2-based cassette" and transformed with an expression vector containing a DNA sequence encoding said heterologous gene under the control of a T4 promoter.

23. The DNA sequence of SEQ ID NO:1.

24. The DNA sequence of SEQ ID NO:2.

ATGGCTTCTA ACCTTCACTC AGTTCGTACT GGTTGACAAC GCGGGTACCG
GCGATGTAAC TGTTGCACCG TCCAACCTCG CAAATGGCGT TGCTGAATGG
ATTTCTTCCA ACTCTCGCAG CCAGGCTTAC AAAGTAACTT GCAGCGTTTCG
CCAGTCCTCT GCACAAAACC GAAAATACAC CATCAAGGTA GAAGTCCCGA
AAGTTGCGAC CCAGACTGTA GCGGGTGTCG AACTGCCGGT TGCTGCATGG
CGCAGCTACC TGAACATGGA ACTGACTATC CCGATTTTCG CAACCAACTC
TGACTGTGAA CTGATCGTAA AAGCTATGCA GGGTCTGCTA AAAGATGGCA
ATCCAATTCC GTCCGCAATC GCTGCAAACCT CTGGTATCTA CTAATAG

FIG.1

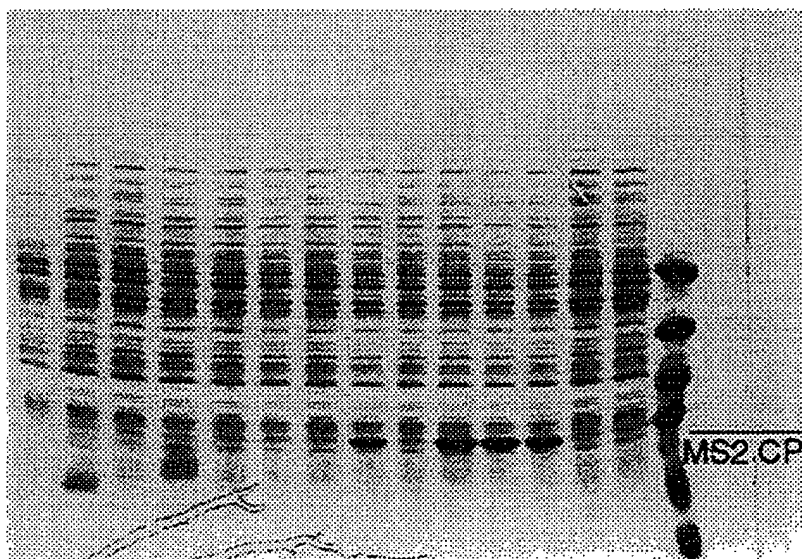
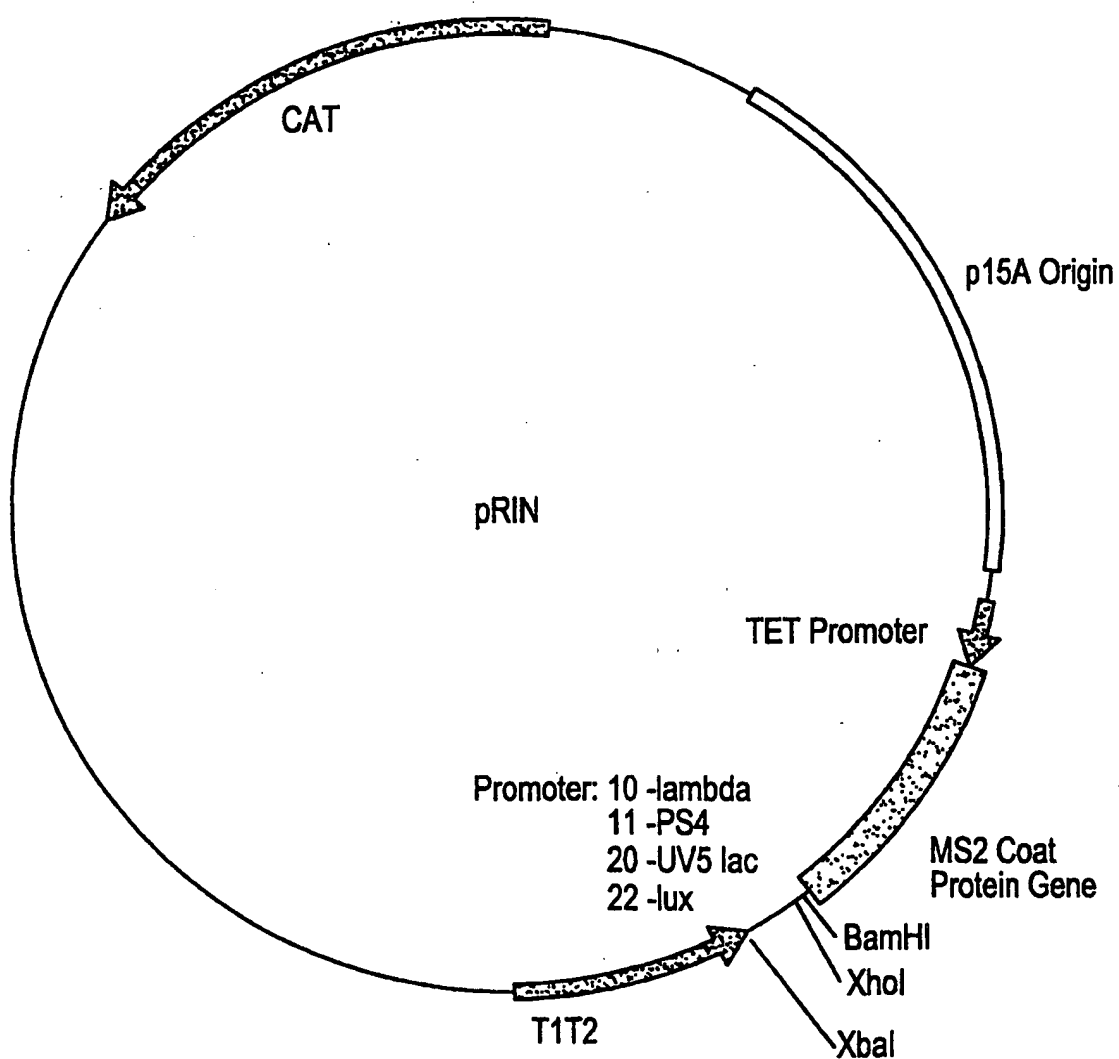


FIG.2

FIG. 3



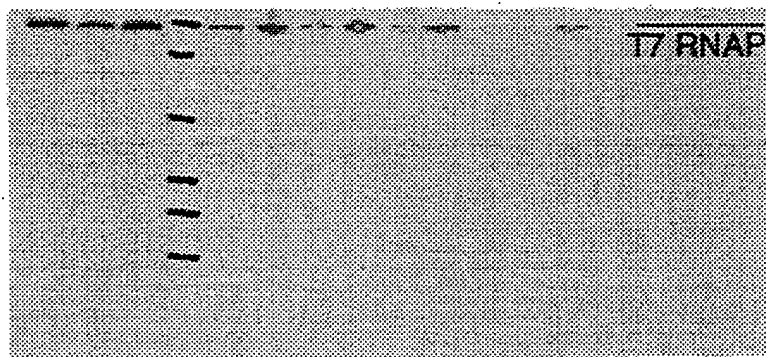


FIG.4

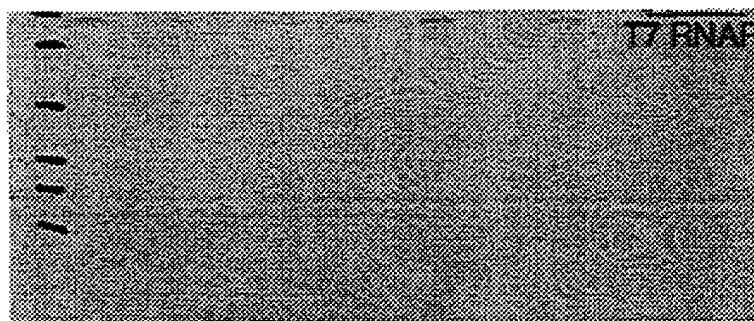


FIG.5

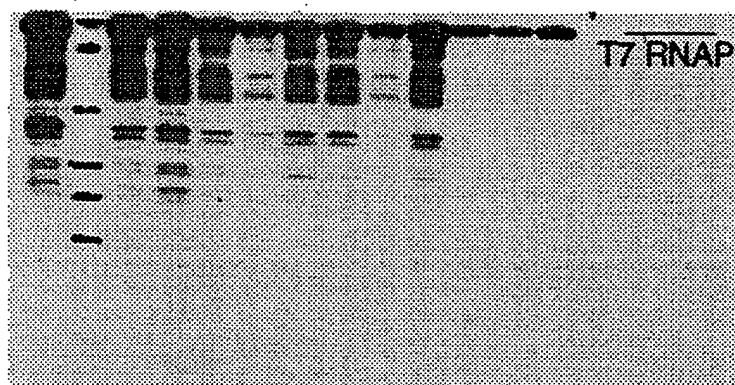


FIG.6

FIG. 7



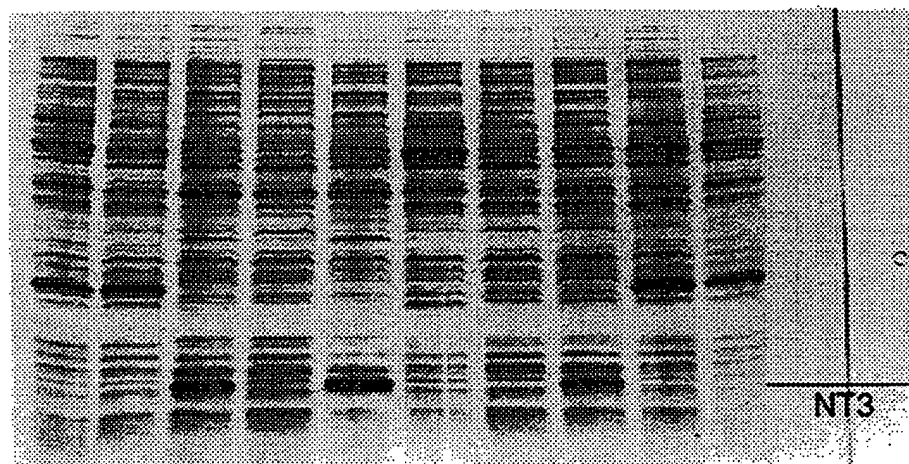


FIG.8

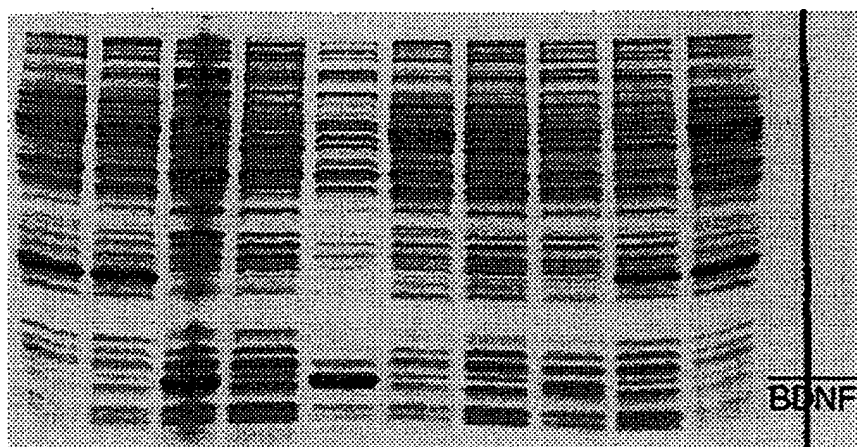


FIG.9

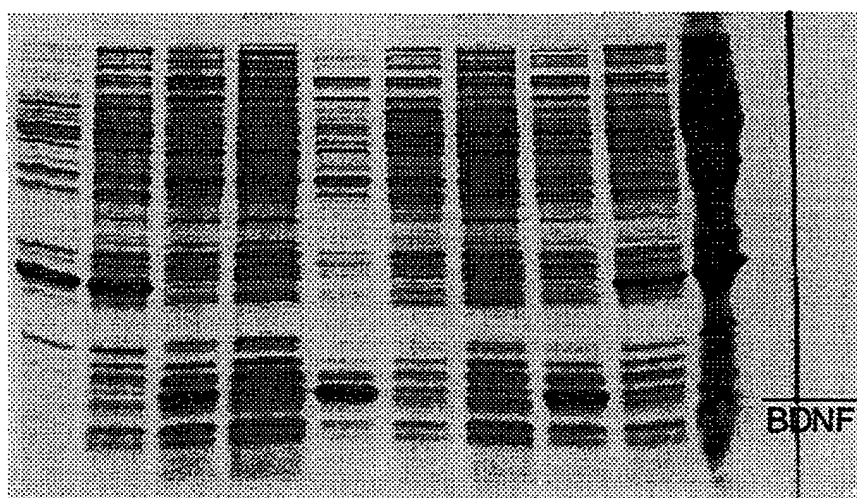


FIG.10

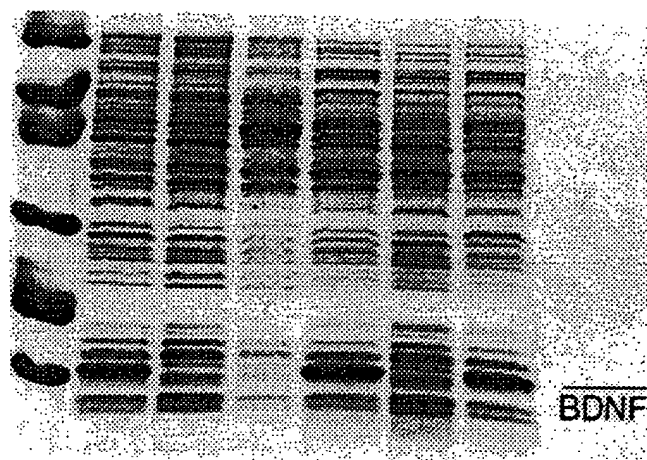


FIG.11

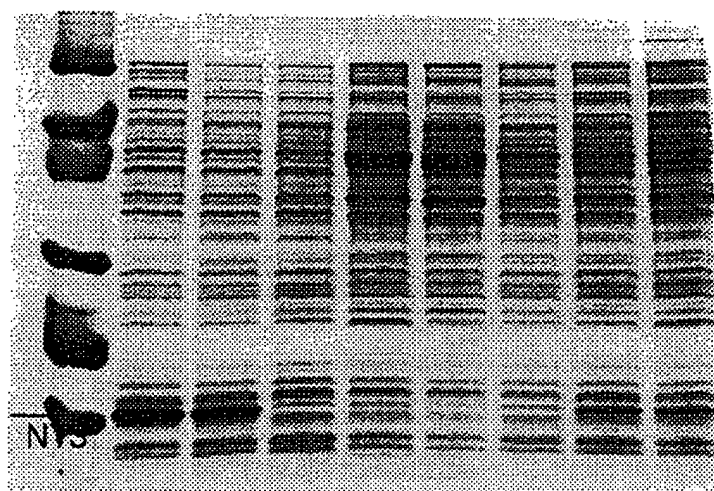


FIG.12

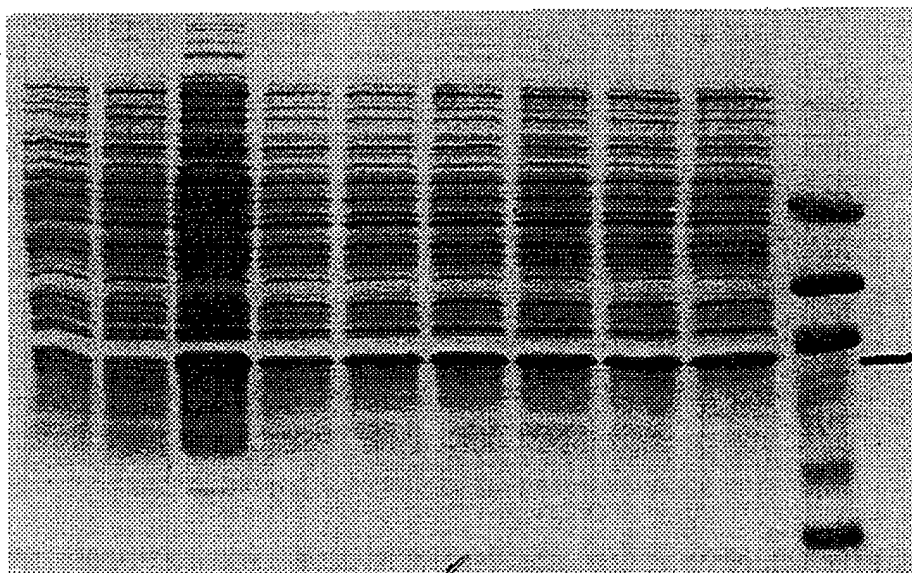


FIG.13

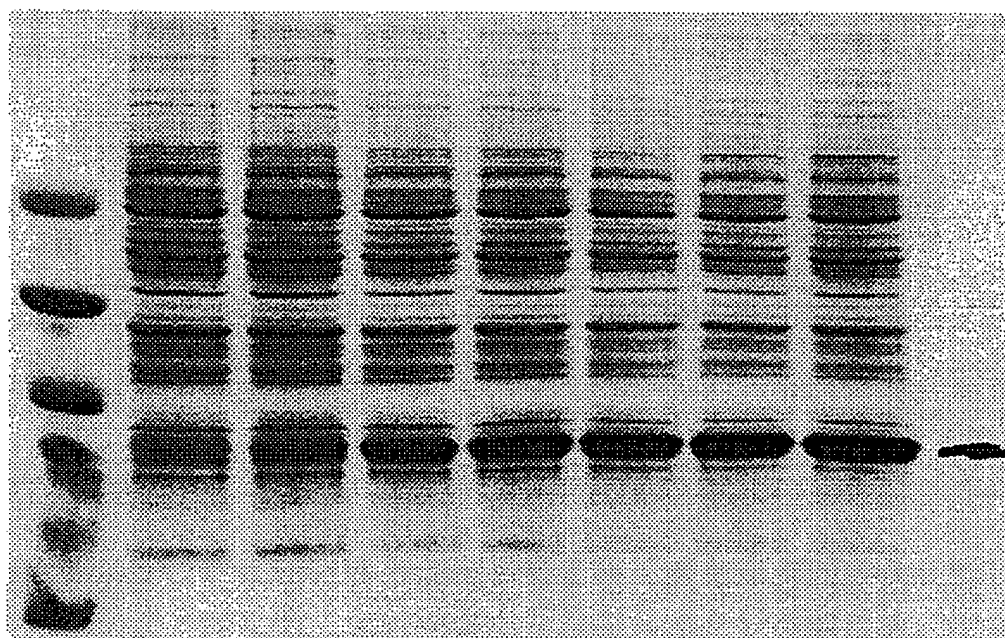


FIG.14

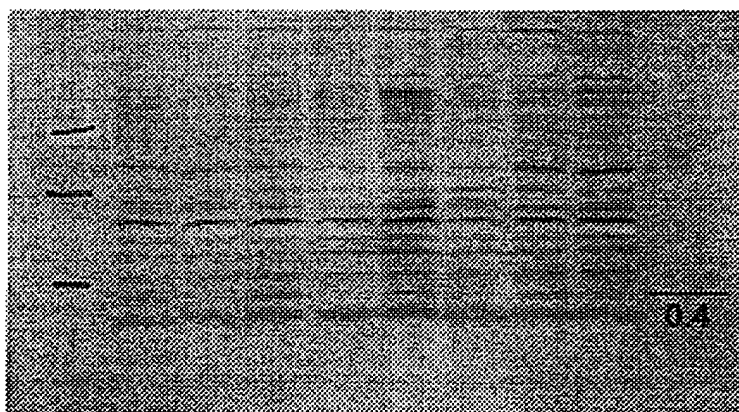


FIG.15

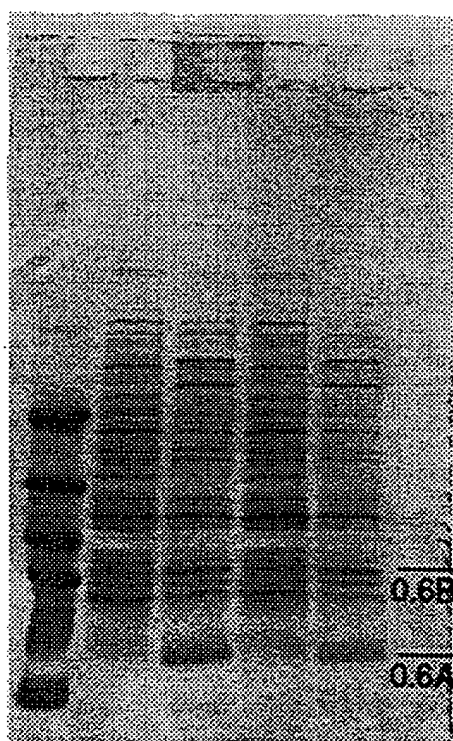


FIG.16

TCTAGAAAAC	ATGAGGATTA	CCCATGGCTA	TGTCTAATCT	CACATATAAC
AACGTTTTTCG	ACCACGCTTA	CGAAATGCTG	AAAGAAAACA	TCCGTTATGA
TGACATCCGT	GACACTGATG	ACCTGCACGA	TGCTATTAC	ATGGCTGCCG
ATAATGCAGT	TCCGCACTAC	TACGCTGACA	TCTTTAGCGT	AATGGCAAGT
GAGGGCATTG	ACCTTGAGTT	CGAAGACTCT	GGTCTGATGC	CTGACACCAA
GGACGTAATC	CGCATCCTGC	AAGCGCGTAT	CTATGAGCAA	TTAACGATTG
ACCTCTGGGA	AGACGCAGAA	GACTTGCTCA	ATGAATACTT	GGAGGAAGTC
GAGGAGTACG	AGGAGGATGA	AGAGTAAAAA	CATGAGGATT	ACCCATGTCT
AATACCAACG	TGCAATACGG	TCTGACCGCT	CAAACGTAC	TTTTCTATAG
CGACATGGTG	CGCTGTGGCT	TTAACTGGTC	ACTCGCAATG	GCACAGCTCA
AAGAACTGTA	CGAAAACAAC	AAGGCAATAG	CTTTAGAACC	TGCTGAGTGA
TAGACTCAAA	CATGAGGATT	ACCCATGTAT	ATGCTTACTA	TCGGTCTACT
CACCGCTCTA	GGTCTGGCTG	TAGGTGCATC	CTTTGGGAAG	GCTTTAGGTG
TAGCTGTAGG	TTCTACTTTT	ACCGCTTGCA	TCATCATAGG	AATCATCAAA
GGGGCACTAC	GCAAATGATG	AAAACATGAG	GATTACCCAT	GCGGCATTAC
GTTATGCCAA	TCCACACGTC	CAACGGGGCA	ACCGTATGTA	CACCTGATGG
GTTCGCAATG	AAACAACGAA	TCGAACGCCT	TGAGCGTGAA	CTCCGCATTA
ACCGCAAGAT	TAACAAGATA	GGTTCCGGCT	ATGACAGAAC	GCACTGATGG

FIG.17 A

CTTAAAGAAA GGTTATATGC CCAATGGCAC ACTATACGCT GCAAATCGGC
GAATAGTGAG AACTTGGCGA GAGAACAACC TCGAACGCCG CAAGGAACAA
GAGAGGGCGG TGTGGCATAG ACGAAAGGAA AAGGTTAAAG CCAAGAAACT
CGCCGCACTT GAACAGGCAC TAGCCAACAC ACTGAACGCT ATCTCATAAA
AACATGAGGA TTACCCATGA ACATTACCGA CATATCAAAC GCTATCGACG
CAATCAAAGC ACTGCCAATC TGTGAACTTG ACAAGCGTCA AGGTATGCTT
ATCGACTTAC TGGTCGAGAT GGTCAACAGC GAGACGTGTG ATGGCGAGCT
AACCGAACTA AATCAGGCAC TTGAGCATCA AGATTGGTGG ACTACCTTGA
AGTGTCTCAC GGCTGACGCA GGGTTCAAGA TGCTCGGTGA TGGTCACTTC
TCGGCTGCTT ATAGTCACCC GCTGCTACCT AACAGAGTGA TTAAGGTGGG
CTTTAAGAAA GAGGATTCAG GCGCAGCCTA TACCGCATTC TGCCGCATGT
ATCAGGGTCG TCCTGGTATC CCTAACGTCT ACGATGTACA GCGCCACGCT
GGATGCTATA CGGTGGTACT TGACGCACTT AAGGATTGCG AGCGTTTCAA
CAATGATGCT CATTATAAAT ACGCTGAGAT TGCAAGCGAC ATCATTGATT
GCAATTCGGA TGAGCATGAT GAGTTAACTG GATGGGATGG TGAGTTTGTT
GAAACTTGTA AACTAATCCG CAAGTTCTTT GAGGGCATCG CCTCATTCGA
CATGCATAGC GGGAACATCA TGTTCTCAAA TGGAGACGTA CCATACATCA
CCGACCCGGT ATCATTCTCG CAGAAGAAAG ACGGTGGCGC ATTCAGCATC
GACCCTGAGG AACTCATCAA GGAAGTCGAG GAAGTCGCAT GATAGCTCGA
G

FIG.17 B

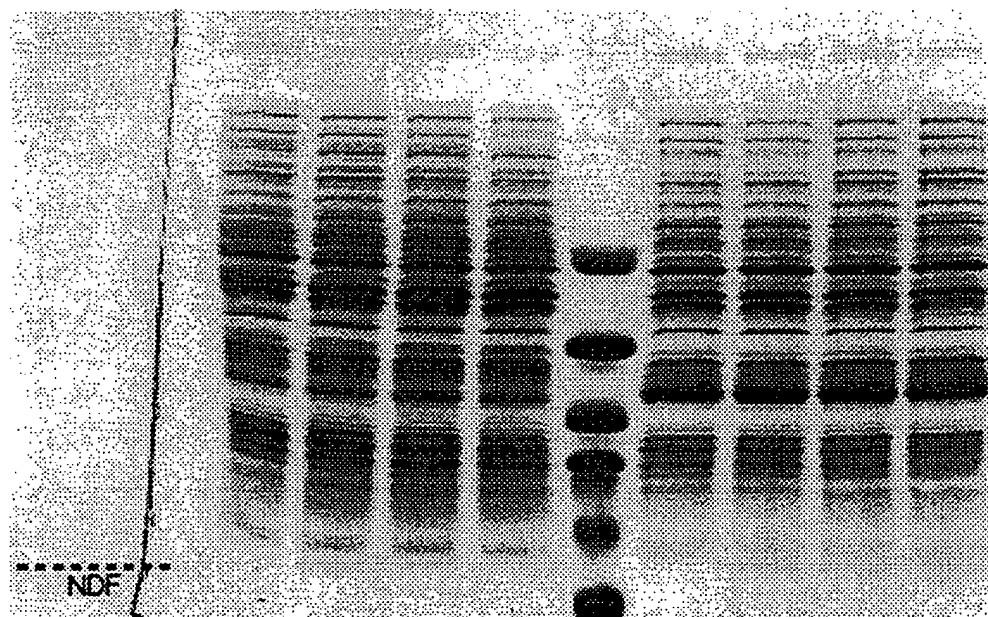


FIG.18

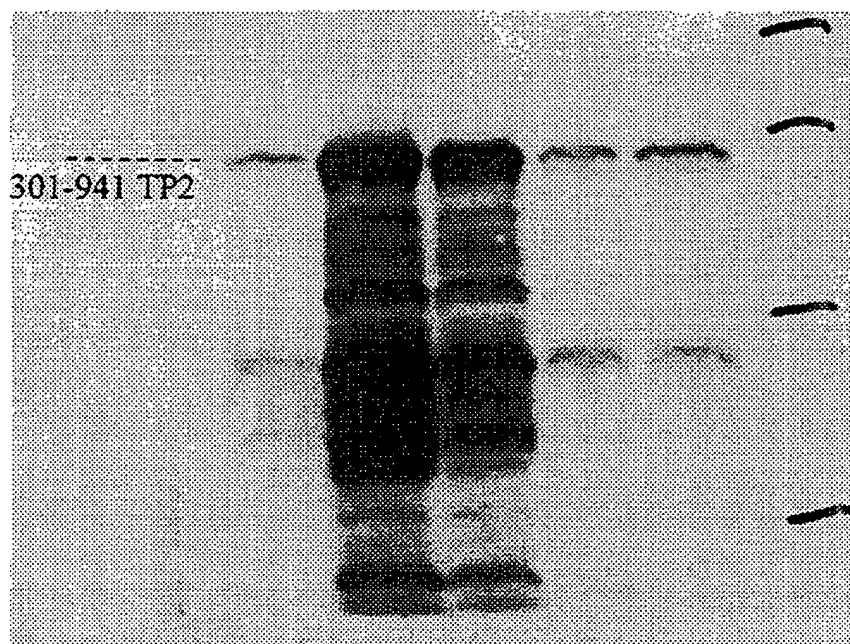


FIG.19

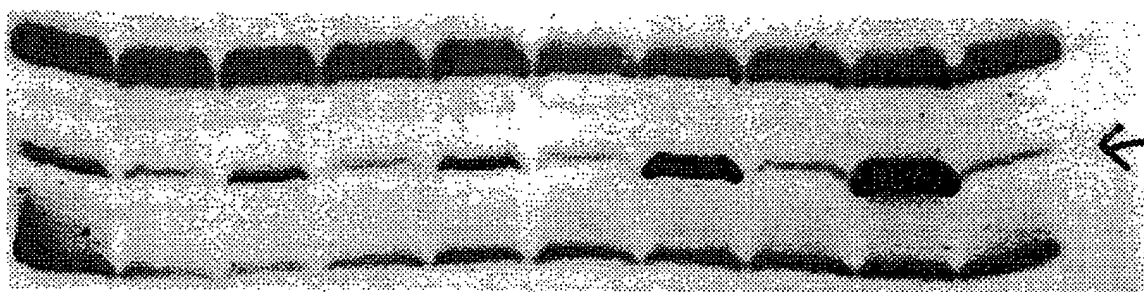


FIG.20

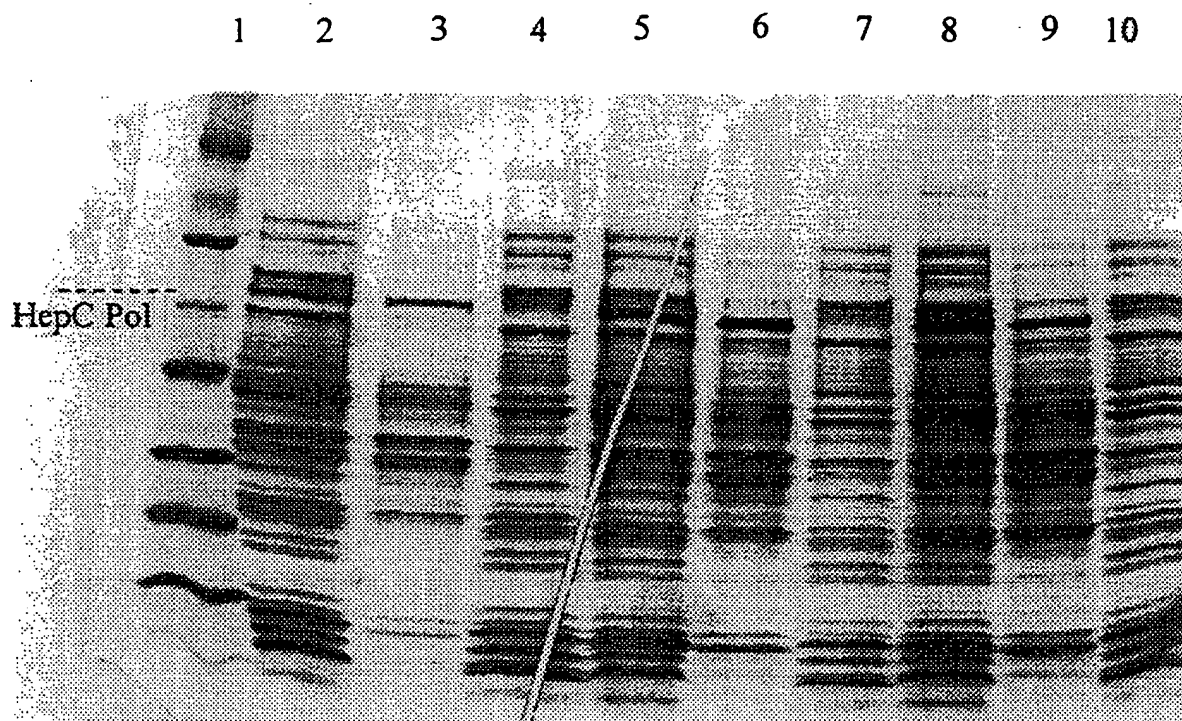


FIG.21

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TAATAATCCA TATGGTTATA ATAGAAATAA ACCATCA

FIG.22

TGATAGAGTC AATGAGTTAA AACACAGTGA TGTTTTGCGT AAAGAGATGC
TTTCTATTCA ACATGATATT TTAAATAAAA CCCGTGC

FIG.23

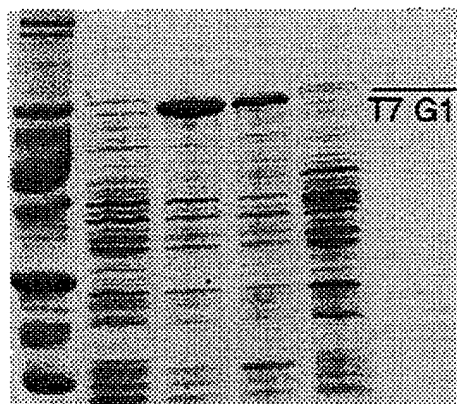


FIG.24

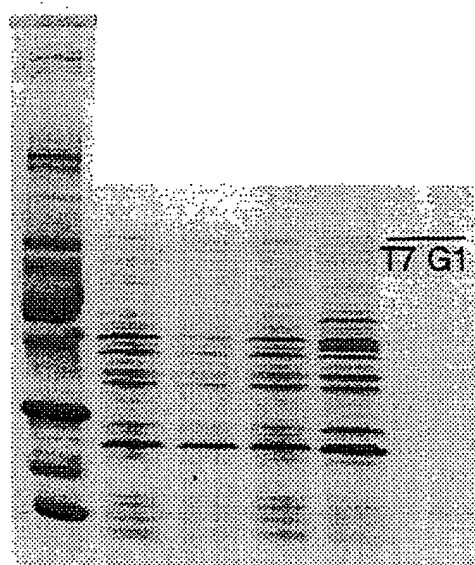


FIG.25

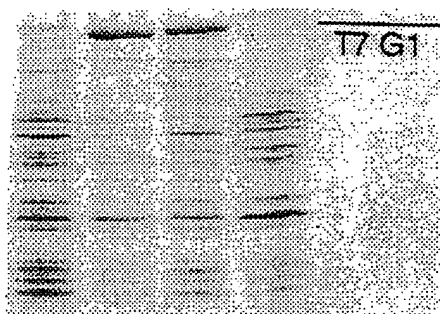
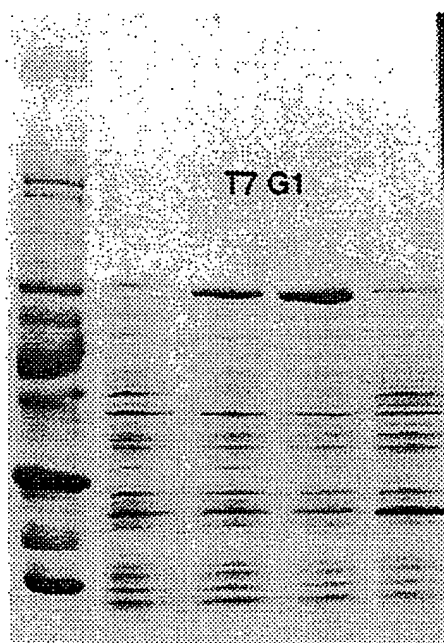


FIG.26

**FIG.27**

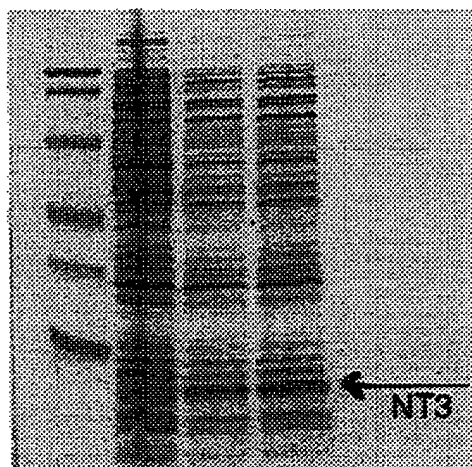


FIG.28

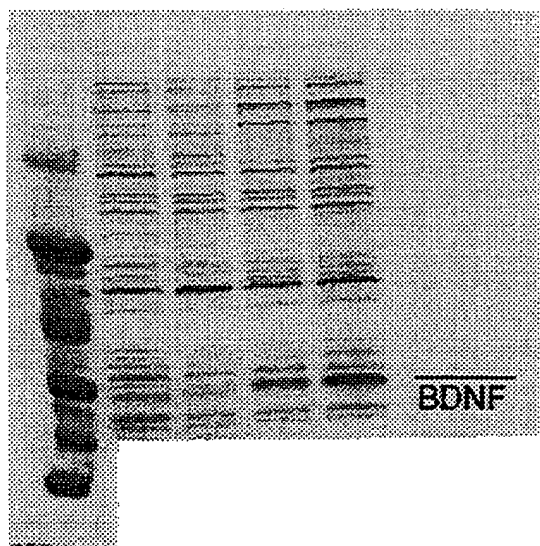


FIG.29

FIG. 30

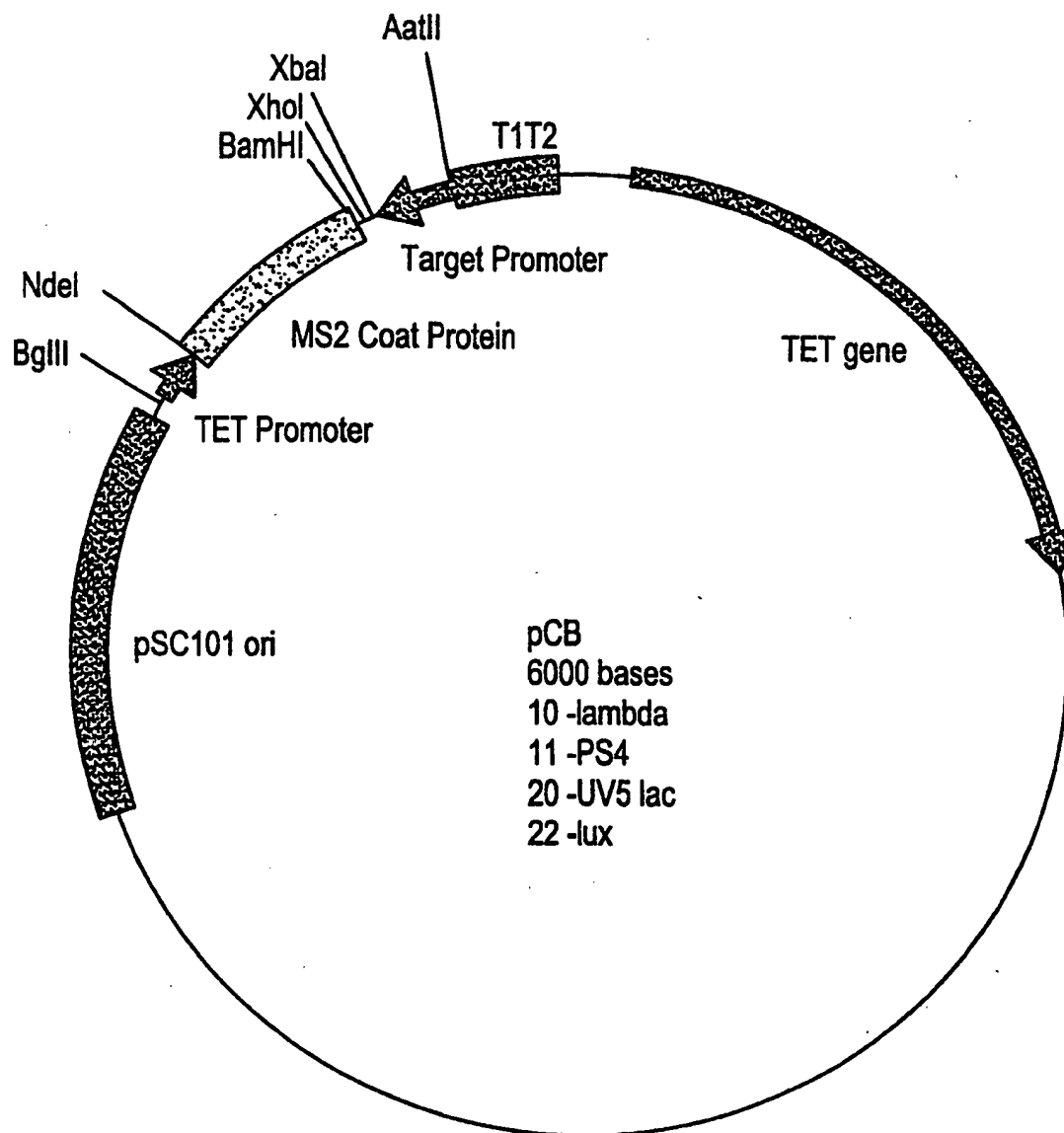
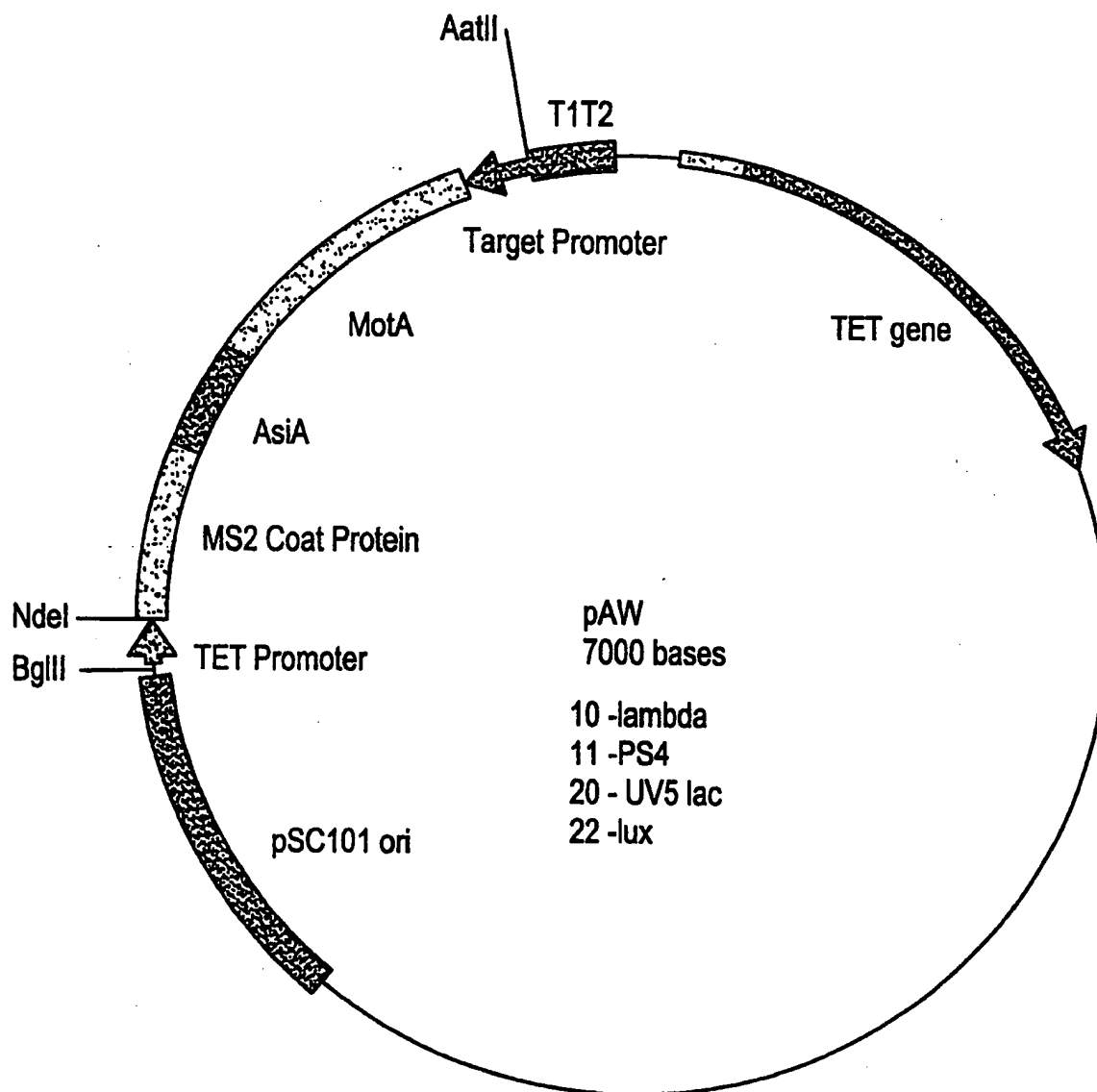


FIG. 31



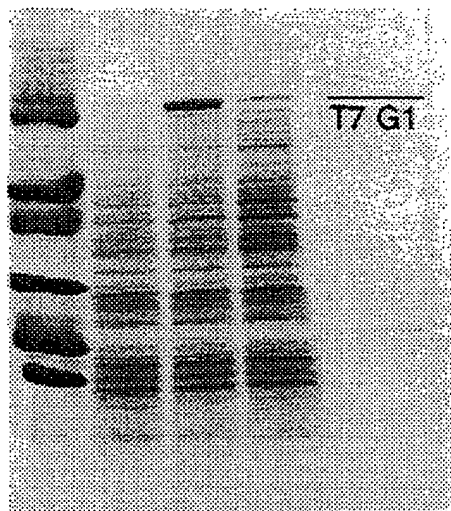


FIG.32

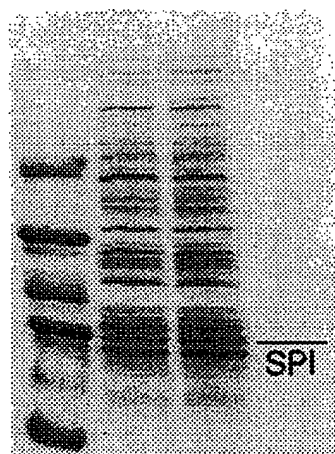


FIG.33

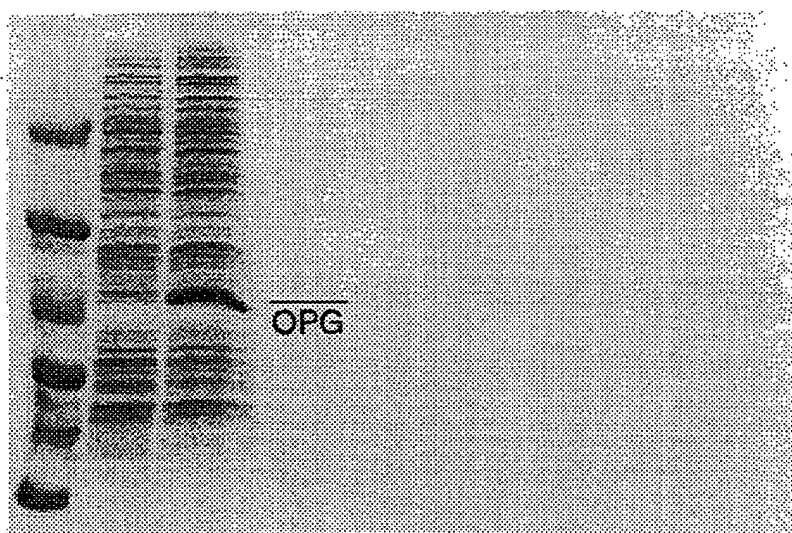


FIG.34

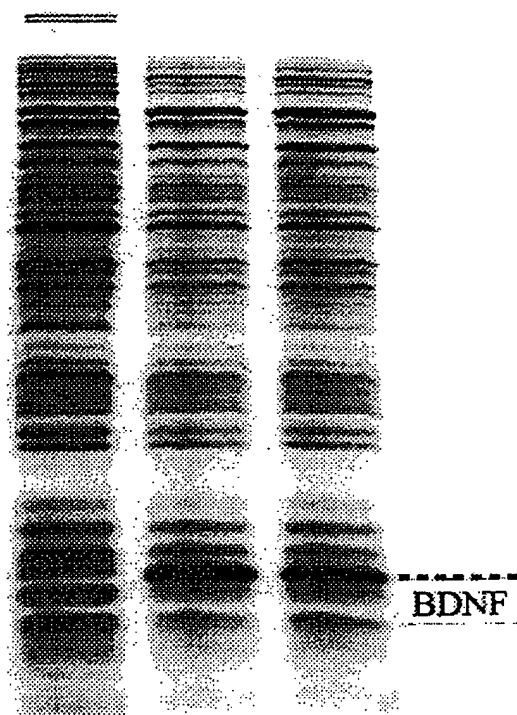


FIG.35

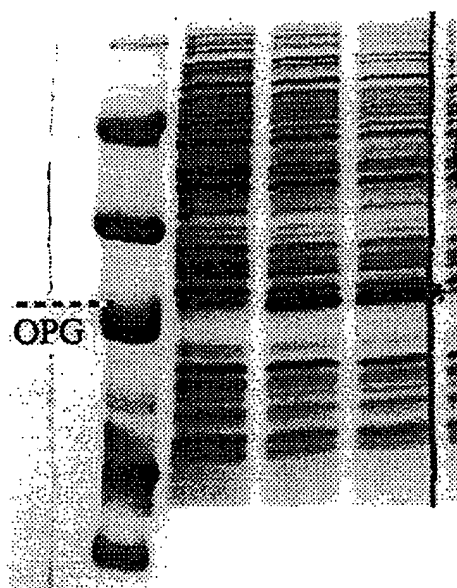


FIG.36

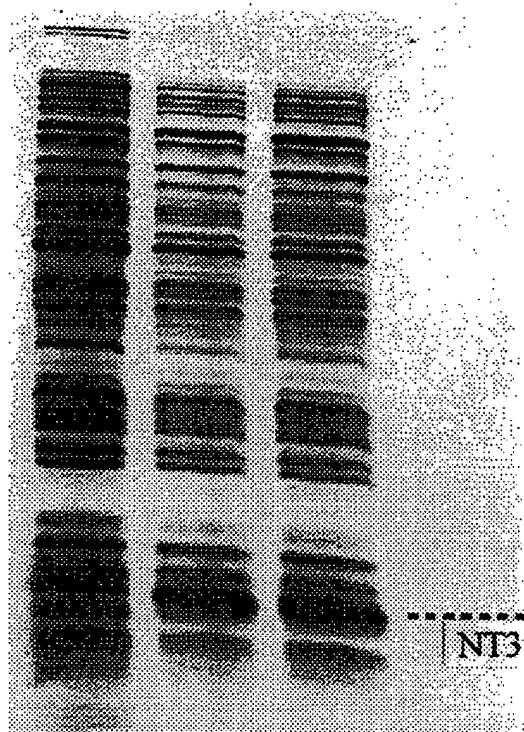


FIG.37

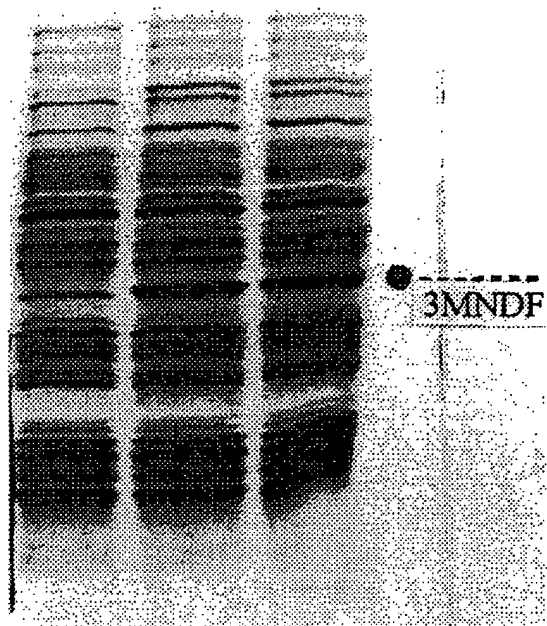


FIG.38

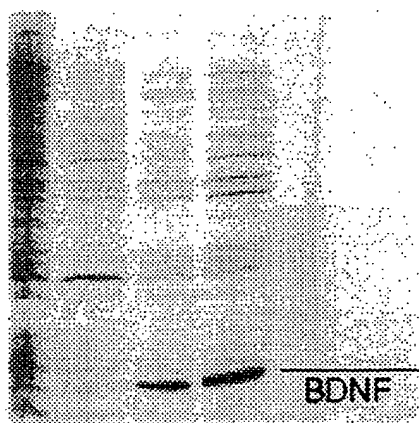


FIG.39

SEQUENCE LISTING

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<140> NOT ASSIGNED YET

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<151> 1998-01-28

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cta 63

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